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UNITED AIR LINES

ENGINEERING FLIGHT EVALUATION REPORT

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Moffett Field, California

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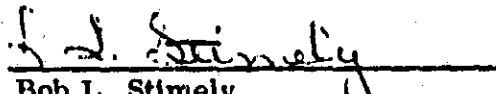
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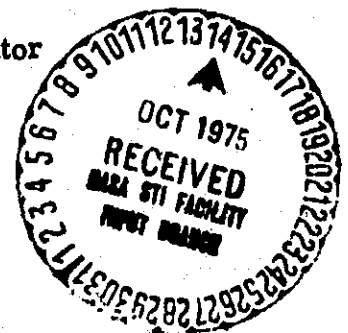


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I. INTRODUCTION

INTRODUCTION

The Engineering Flight Evaluation is the second of four major phases of the B-727 Two-Segment Approach Program as outlined below. This program is being conducted by United Air Lines under contract to the National Aeronautics and Space Administration Ames Research Center.

Initial development work for the program was carried out in a B-727-200 flight simulator at United Air Lines Flight Training Center in Denver. The results of the Simulation Evaluation phase are detailed in a separate interim report. The Simulation Evaluation Report also contains detailed background discussions of profile and equipment design philosophy.

The purpose of the Engineering Flight Evaluation, the phase reported herein, was to determine if the two-segment profile, equipment, and operational procedures as defined by the Simulation Evaluation are operationally sound for use in line service.

At the conclusion of the Engineering Flight Evaluation, the system was evaluated by 55 pilots representing numerous airlines and other organizations in the Off-Line Guest Pilot Evaluation. The system was then put into revenue service for the final phase, a six-month On-Line Pilot Evaluation. Results of these final two phases will be included in the Final Report, to be issued in early 1974.

II. SUMMARY

SUMMARY

The primary objective of the Engineering Flight Evaluation was to determine if the two-segment profile, equipment, and operational procedures as defined by the B-727 Simulation Evaluation are operationally sound under all flight conditions expected to be encountered in line service. In order to achieve this goal, the evaluation was divided into the following areas of investigation:

1. To verify that the two-segment system operates as it was designed.
2. To conduct sufficient tests to secure a supplemental type certificate for line operation of the system.
3. To evaluate the normal operation of the equipment and procedures.
4. To evaluate the need for an autothrottle system for two-segment approaches.
5. To investigate abnormal operation of the equipment and procedures, including abused approaches and malfunctions of airborne and ground components.
6. To determine the accuracy and ease of flying the two-segment approach.
7. To determine the improvement in ground noise levels.
8. To develop a guest pilot flight test syllabus.

The evaluation was successfully conducted in two airplanes (Ansett B-727-277 VH-RMU and United B-727-222 N7640U) in 136 flying hours making 377 approaches. At the completion of the evaluation the system was certified by the FAA and placed into line service for an operational evaluation of the concept. A Collins glide slope computer system was installed in the airplane to provide guidance on a basic two-segment approach profile with an initial altitude of 3000' to 12,000' MSL, a smooth capture and push-over to a 6° upper segment, a smooth capture and lower transition to the glide slope such that the airplane is stabilized on the glide slope at or above 500' above the runway touchdown zone.

The results of the Simulation Evaluation were verified by the Engineering Flight Evaluation. The two-segment approach system, the operational profile and procedures were determined to be operationally sound for routine line service.

SUMMARY - Continued

The operation of the two-segment approach system is the same as a standard ILS approach with the additions of setting the Airport Elevation Panel to the field elevation and turning on the two-segment approach switch. The two-segment approach can be flown with the same airspeed and airplane configuration as is currently used for the B-727. An optional ten knot increment while on the upper segment also produced good results. The pilot workload is increased slightly due to the need to transition from the upper segment to the glide slope. The pilot must pay more attention to his flight technique during and after this transition. The approach is not adversely affected by weather conditions except during icing conditions which require high minimum rpm on the approach, or tailwind conditions exceeding 20 knots which require idle thrust on the upper segment.

The abnormal operation and system component failures are similar to the standard ILS system. There are adequate safe-guards and warnings to alert the pilot to these in plenty of time for him to take decisive action.

The autothrottle system installed in the aircraft operates adequately but is overly aggressive during operations when the air is turbulent. Evaluation results indicate that an autothrottle is not required to make two-segment approaches.

The two-segment system provides guidance which accurately follows the desired nominal two-segment path. The transitions are adequate, although some improvements could be made. Overall performance is good and the accuracies are acceptable for low visibility flight conditions.

The determination of the reduction in ground noise levels due to use of the two-segment approach is beyond the scope of this report. However, noise measurements made during and subsequent to the Engineering Flight Evaluation verified that the procedure yields significant noise level reductions.

III. TEST STRUCTURE

- A. Airplanes and Equipment**
- B. Test Procedure and Organization**
- C. Maintenance Flights**
- D. Avionics Verification Flights**
- E. Noise Measurement Flights**
- F. STC Flights**
- G. Data Systems**

A. Airplanes and Equipment

Two test airplanes were used in the Engineering Evaluation: a B-727-277, No. VH-RMU, leased from Ansett Airlines and a United Air Lines B-727-222, No. N7640U, which was used in line service for the six-month Two-Segment Approach Evaluation at the completion of out-of-service evaluations. There are some basic differences in the two airplanes which provided for a broader equipment evaluation of the two-segment approach.

DIFFERENCES TABLE		
	ANSETT VH-RMU	UAL N7640U
Maximum Gross Weight	190,000 lbs	172,000 lbs
Engines	JT8D-15 Acoustically treated	JT8D-7 Non-treated
Flight Director	FD-108 4" ADI	FD-109A 5" ADI
Flight Director Modes	Speed	Steer
	Heading	Flight Instruments
	VOR/LOC	VOR/LOC
	Auto G/S	Auto App
	Manual G/S	Manual G/S
Autopilot	SP-50	SP-50
Autopilot Modes	Mach Hold	-
	ILS Hold	-
	Vertical Speed	-
	Pitch Hold	-
	Heading Select	Heading Select
	Altitude Select	-
	Altitude Hold	Altitude Hold
	Aux Nav	-
	NAV/LOC	NAV/LOC
	Turn Knob	Manual
	Auto G/S	Auto G/S
	Manual G/S	Manual G/S
DME	Single ARINC 568 (Digital)	Dual ARINC 521 (Analog)
Autothrottle	Provisions	Not Installed
Altimeter	Smith Servoed Counter	Kollsman Standby Servo-
	Drum Pointer	Pneumatic
Air Data Computer	Honeywell HG180U-97	Honeywell HG180U-64
Instrument Comparison	Collins 54W-1B	Not Installed

TABLE 1.

A. Continued

The two-segment avionics system consisted of the following components:

1. Collins 562A-13 Two-Segment Approach Computer
2. Collins 161E-11 Two-Segment Approach Switching Unit
3. Collins 614E-39 Two-Segment Airport Elevation Setting Unit
4. Collins Two-Segment Selector Switch

The system interfaced with the Captain's instruments only.

The 562A-13 two-segment approach computer provides the required guidance information to the existing aircraft systems. Outputs on the upper segment include the rate sensitive captures, deviation and tracking information to the flight director and/or autopilot; raw data deviation to the HSI; and the incremental bias to the autothrottle system. It also provides the rate sensitive capture and autopilot DME gain programming of the glide slope as well as all mode and annunciation logic for the entire approach.

The 161E-11 two-segment switching unit modifies the airplane interconnect and substitutes the two-segment computations for the standard information and switches the appropriate autopilot and flight director mode lines.

The 614E-39 two-segment airport elevation setting unit provides for pilot input of the airport touch down zone altitude to permit variable initial intercept altitudes.

The two-segment selector switch is the means by which the pilot inputs his "decision" to make a two-segment approach rather than a standard ILS.

B. Test Procedure

The Flight Evaluation Test team consisted of a Project Pilot in the Captain's position, a Project Pilot in the First Observer's position, and a Project Flight Engineer in the Second Officer's position. Additional crew members on board were an instrumentation engineer and a Flight Test Engineer. Most flights had other observers on board with various interests in the flight test being conducted.

B. Continued

The pilot in the Captain's position flew the approach and made the evaluation for that approach. The pilot directly behind observed the performance and made an additional evaluation as well as recording the Captain's evaluation. The pilot in the First Officer's position constantly monitored the aircraft flight condition and kept visual contact outside of the cockpit. In event of a compromise to flight safety, he was to take over and/or remedy the situation. The Flight Test Engineer acted as coordinator between the other working parties on the aircraft and the flight crew.

At the initiation of an approach, prior to the upper capture point, the Flight Engineer (Second Officer) would enter the approach number into the data recording systems (see page 16 and Appendix II) and announce commencement of the approach. If the video recorder was being used during this approach, the cameraman would start recording at that time. The Captain flew the approach, making comments during its course. The Project Pilot in the observer's seat marked his evaluation and recorded his and the Captain's comments. The First Officer supported the Captain in the approach and maintained the necessary inside and outside cockpit monitoring necessary for flight safety. The First Officer would also fly the airplane from the missed approach to the initiation of the next approach while the first observer and the Captain discussed the approach just flown. This procedure provided adequate flight safety since the right-seat pilot (First Officer) could monitor the airplane performance, cross-checking his instruments and clearing outside.

The First Officer's tasks were based upon the fact that the right-seat pilot was greatly limited in ability to determine the exact indications of the Captain's instruments and to observe the Captain's flight technique while at the same time maintaining the degree of flight safety demanded by airline operations. The First Observer's location was the optimum position for the Project Pilot to interpret the exact indications of the Captain's instruments and observe the flight technique being used.

B. Continued

The United Air Lines Project Team consisted of the following personnel:

John A. Morrison, Lead Project Pilot
Tom H. Branch, Project Pilot
Hugh L. Monteith, Project Pilot
Floyd E. Snyder, Project Pilot
Vince V. Hagan, Flight Engineer
George H. Martin, Flight Engineer
David J. Walkinshaw, Flight Engineer

In addition to the Project Team, United Air Lines B-727 Fleet Manager Captain Robert L. Stimely and NASA Project Pilot Fred. J. Drinkwater participated in the Engineering Flight Evaluation.

The flight evaluation program consisted of four basic types of test flights made in the two airplanes: Maintenance, Avionics Verification, STC, and Engineering Evaluation. Noise measurements were taken in conjunction with Engineering Evaluation flights. Twenty-nine flights including 245 approaches were made in the Ansett airplane in a total of 94:00 flight hours (ref. Table 2). Fourteen flights and 132 approaches were made in the United airplane in 41:05 flight hours (ref. Table 3).

C. Maintenance Flights

The Maintenance Test Flights were operated in accordance with the United Air Lines Maintenance Flight Test Handbook. The Ansett flight was on 12/8/72 and the UAL flight was on 4/7/73. (Initial maintenance flight test outlines are included in Appendix IV.)

The standard ILS system operated normally, both flight director and autopilot, during the initial maintenance flights. There was no interference by the two-segment system with any of the other airplane systems.

ANSETT VII-RMU

FLT NBR*	DATE	PURPOSE	STF	ILS	TWO-SEGMENT	
			F/D	A/P	F/D	A/P
1	12/8/72	Maintenance	2	2	3	4
2	12/9/72	STC	1		1	
3	12/10/72	Engineering Evaluation		3	1	3
4	12/11/73	" "	2	2	2	6
6	12/12/72	STC		1		6
9	12/14/72	Engineering Evaluation	1	1		
11	12/16/72	" "		1	3	4
12	12/19/72	" "		1	2	2
13	12/20/72	" "	1	1	3	5
14	12/26/72	" "		1	2	7
15	12/29/72	" "		1	6	14
16	1/1/73	" "		1	1	5
17	1/4/73	" "	2	1		7
18	1/15/73	" "	3	1	7	12
19	1/6/73	" "			2	14
20	1/7/73	" "		2	3	6
21	1/10/73	" "		5		19
22	1/11/73	STC		2		2
23	1/12/73	Engineering Evaluation		4	2	6
26	1/15/73	" "	1		1	2
27	1/16/73	" "	1	1	4	3
28	1/17/73	" "				4
32	1/21/73	" "			2	2
35	1/24/73	Engineering Eval./STC				2
42	1/31/73	Engineering Evaluation			(2 raw data)	
44	2/2/73	" "	1	1	3	4
48	2/6/73	" "			3	1
51	2/8/73	" "			5	
52	2/14/73	Maintenance (Return to Config.)	1	1		
TOTALS			16	33	56	140

TABLE 2

ENGINEERING FLIGHT APPROACHES

* Flight numbers not listed were guest pilot evaluation flights.

F/D - Flight Director approach

A/P - Autocoupled approach

UAL N7640U

FLT NBR*	DATE	PURPOSE	STD	ILS	TWO-SEGMENT	
			F/D	A/P	F/D	A/P
1	4/6/73	Maintenance/Engr. Eval	2	2	1	5
2	4/7/73	Engineering Evaluation			3	6
3	4/8/73	" "			2	2
4	4/9/73	" "			3	2
5 &	4/12/73	" "				
6	"	" "	1	1	3	7
7 &	4/13/73	" "				
8	"	" "	1	1	3	7
9 &	4/17/73	" "				
10	"	" "	1	1	5	7
11	4/20/73	STC	1	1	1	11
12	4/26/73	Engineering Evaluation			4	4
13	5/14/73	Noise Measurements	3	3	3	3
14	5/15/73	" "	9	3	3	3
TOTALS			18	12	31	71

TABLE 3

ENGINEERING FLIGHT APPROACHES

* Flight numbers not listed were guest pilot evaluation flights.

D. Avionics Verification Flights

The flights on 12/10/72 and 12/11/72 were flown to verify the proper functioning of the two-segment system prior to the STC flight on 12/12/72.

The upper angle of the two-segment approach was set at the maximum value of the variable (7°) and the lower intersect altitude raised to 1500 feet AFL. This angle was selected as it was the steepest angle expected to be flown by the airplane during the two-segment evaluation and provided the most severe test for a nose-down hard-over elevator command to be made during the STC flight. The 1500 foot lower altitude provided the flight safety aspect for the initial hard-over failure test. Hardover failure test results are contained in Appendix II.

E. Noise Measurement Flights

Forty-nine noise measurement approaches were made in the Ansett airplane, which was equipped with the acoustically treated JT8D-15 engines. Thirty noise measurement approaches were made in the United airplane, which was equipped with the non-treated JT8D-7 engines. These approaches are tabulated in Table 4 and Table 5. The first noise measurement series (Table 4) indicated the relative noise improvement with change in profile geometry as well as the noise pattern with acoustically treated engine nacelles. The second noise measurement series (Table 5) was made with the operational geometry to be used for the in-service evaluation. The results of these measurements are contained in reports NASA CR 144691 and NASA CR 144689 prepared under Contract No. NAS2-7369 by Hydrospace Research Corporation, San Diego, California.

ANSETT AIRCRAFT VH-RMU - JT8D-15 ENGINES

NBR OF APPROACHES MADE	TYPE OF APPROACH	FLAP SETTING	ANGLE INTERCEPT	FLIGHT DIRECTOR (F/D) AUTOCOUPLED (A/C) AND AUTO/MANUAL THROTTLE	
6	Standard ILS	30°	2.9°	A/C	A/T
6	"	"	2.9°	A/C	M/T
3	"	40°	2.9°	A/C	A/T
3	"	"	2.9°	A/C	M/T
8	Two-Segmt	30°	6°/690	A/C	A/T
8	"	"	"	A/C	M/T
4	"	"	6.5°/500	One Dot High	
3	"	"	6°/1000'	A/C	A/T
3	"	"	6°/500'	A/C	M/T
2	"	"	5.2°/690'	A/C	M/T
3	"	"	6.5°/690'	A/C	M/T
4	Standard ILS	Delayed	2.9°	F/D	M/T

Flown 1/10/73 and 1/26/73 thru 1/30/73

NOISE MEASUREMENT APPROACHES

TABLE 4

UAL AIRCRAFT N7640U - JT8D-7 ENGINES

NBR OF APPROACHES MADE	TYPE OF APPROACH	FLAP SETTING	ANGLE INTERCEPT	AUTOCOUPLED (A/C) FLIGHT DIRECTOR (F/D)	
6	Standard ILS	30°	2.9°	3 A/C	3 F/D
6	"	40°	"	3 A/C	3 F/D
6	"	Delayed Flaps	"	6 F/D	
6	Two-Segmt	30°	6°/690'	3 A/C	3 F/D
6	"	40°	6°/690'	3 A/C	3 F/D

Flown 5/14-15/73

NOISE MEASUREMENT APPROACHES

TABLE 5

F. STC Flights

Four flights were conducted to obtain Supplemental Type Certificates to operate two-segment approaches. The FAA Western Region Office issued the STC's. The table below summarizes the certification flights.

	DATE	AIRPLANE	PRIMARY OBJECTIVE	TIA NO.
1	12/09/72	VH-RMU	Normal Systems	T4990WE-DS
2	12/12/72	VH-RMU	Two-Segment System	"
3	1/24/73	VH-RMU	Autothrottle System	"
4	4/20/73	N7640U	All Systems (Autothrottle not installed)	T5209WE-S

TABLE 6
STC FLIGHTS

The following general requirements were established for the STC flights.

1. Approaches must be flown at two or more airports.
2. Approaches must be flown under day and night conditions.
3. Approaches should be flown in crosswind or wind shear conditions.
4. Check normal system operations.
5. Determine that no interface interference exists.
6. Check all failure warnings.
7. Examine all areas where abnormalities might arise.
8. Establish minimum and maximum intercept altitudes.
9. Approve or amend flight manual content pertinent to the two-segment approach for routine airline operation.

Supplemental Type Certificate No. SA2618WE was issued for the Ansett airplane No. VH-RMU and Certificate No. SA2679WE was issued for UAL airplane No. N7640U. (See appendix for details of TIA No. T4990WE-DS and TIA No. T5209WE-S.)

During the STC flights, all airplane systems were operated with the two-segment system ON and OFF. All components of the two-segment approach system functioned as designed without any interference from any airplane system during the approach. There was no interference with any airplane system with the two-segment switch in OFF position.

G. Data Systems

The test flights were documented by four data systems:

1. Flight Data Card
2. Digital Flight Data Recorder
3. Oscillograph Recorder
4. Video Tape Recorder

Each flight had a set of data cards, one for each approach, prepared and placed in the order in which they were to be flown. The Pilot of each flight used these cards during the pre-flight briefing and the post-flight debriefing. All necessary information for a particular approach was entered upon the card. The Pilot Observer worked with the Pilot, ensuring that the equipment was properly set according to the Flight Data Card and that the other data systems were operating as desired. The Pilot Observer entered his remarks on the Flight Data Card upon completion of the flight. At the post-flight debriefing, the Pilot wrote his comments on the Flight Data Card for the approaches that he flew. (See Appendix II for copies of the Flight Data Cards.)

The digital flight data recorder, with its supporting flight data acquisition unit and cockpit entry panel was the primary documentation system for the flight test program. The system recorded 90 parameters which were printed in several different formats for analysis of various aspects of the Flight Evaluation. Details of the digital system are included in Appendix II.

The oscillograph recorder was mounted in the airplane cabin and served as a back-up system for the digital system and, on occasion, provided immediate in flight analysis of an approach by engineering personnel on board.

The video tape recorder was used on the STC flight of 4/20/73, and the preparation flights prior to it. The camera was hand-held by a technician and recorded the Captain's instrument panel during the approach. The playback included audio as well as video. It served to verify comments about the approach and provided details of the two-segment system operation in both normal and abnormal situations.

IV. RESULTS

- A. Normal Operation**
- B. Abnormal Operation**
- C. Autothrottle Operation**
- D. Statistical Analysis**

A. Normal Operation

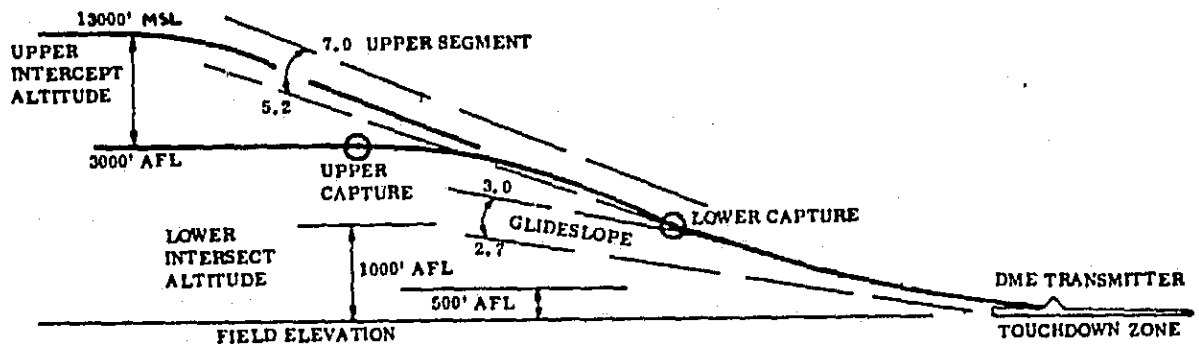
Extensive investigation was made of the approach variables and procedures in order to verify the results of the Simulation Evaluation and to make sure that the best possible two-segment approach was used for the line service evaluation. The areas of investigation were:

1. Profile Variations
 - (a) Upper intercept angle
 - (b) Upper transition
 - (c) Upper segment angle
 - (d) Lower transition
 - (e) Lower intersect altitude
 - (f) Glide slope angle
2. Airspeed Schedule Variations
3. Configuration Schedule Variations
4. Raw Data Presentation
5. Safety Protectors
6. Two-Segment Instrument Presentation
7. Co-Pilot Instrumentation Presentation
8. Weather Effects
 - (a) Low visibility
 - (b) Lighting
 - (c) Winds
 - (d) Turbulence
9. Gross Weight and Center of Gravity Effects
10. Emergency and Irregularities
11. Pilot Workload
12. Fuel Saving

A. Continued

1. Profile Variations

Figure 1 shows the variations in profile parameters which were evaluated during the Engineering Flight Evaluation. The basic two-segment approach profile used was: upper intercept altitude 3000' above touchdown zone, upper segment angle 6°, lower intersect altitude 690' above touchdown zone for a 2.9° glide slope. The upper capture point was such that when approaching the upper segment at 160 knots, the capture occurred when the HSI indicated two dots (500') below the upper segment. The lower capture point occurred when the aircraft was about 300' above the ILS glide slope.



TWO-SEGMENT PROFILE
VARIATIONS

FIGURE 1

NOTE: Angles in all figures in this report are exaggerated 3 to 10 times for clarity.

A. 1. Continued

The basic profile was determined during the Simulation Evaluation. The simulation study indicated that the B-727 could fly this profile operationally except in conditions where full anti-icing capability is required. This basic profile was varied throughout the range of the parameters shown to verify the simulation predictions and to provide a tested operationally suited two-segment approach for routine airline use. Each of the profile parameters is discussed separately on the following pages.

(a) Upper Intercept Altitude _____

The limit altitude for upper segment capture is 13,000' MSL. Intercept altitudes above 14,000' MSL resulted in a steeper upper segment angle to the 14,000 feet point. The two-segment system functions adequately and the transition is smooth and hardly perceptible at 14,000 feet or lower intercept altitudes. The only problem of note associated with the higher altitudes is that the descent starts at a much greater range. In most instances, it is desired to keep the speed high at those ranges. The B-727 does have an inflight speed brake and relatively high drag characteristics in the landing configurations that enable the airplane to slow down even though it is descending at a higher than standard approach altitude and at steeper than standard descent angles. An airplane nominally making a two-segment approach at San Francisco would leave 4,000' MSL outside of 8 miles. If the initial altitude were 10,000' MSL, the descent would begin nearly ten miles further out (ref. Table 7).

The system performs properly for upper intercepts below 3000' AFL but the resulting profiles do not contribute sufficiently to noise abatement since only a small portion of the approach is flown at a lower power setting and higher altitude than a standard ILS. Lower upper intercepts also do not allow sufficient time to stabilize on the upper segment prior to glide slope capture.

A. 1. (a) Continued

CAPTURE RANGES

INITIAL ALTITUDE (AFL)	NOMINAL CAPTURE RANGE (NM)
3,000	6.6
4,000	8.2
5,000	9.8
6,000	11.5
7,000	13.1
8,000	14.7
9,000	16.3
10,000	18.0

TABLE 7

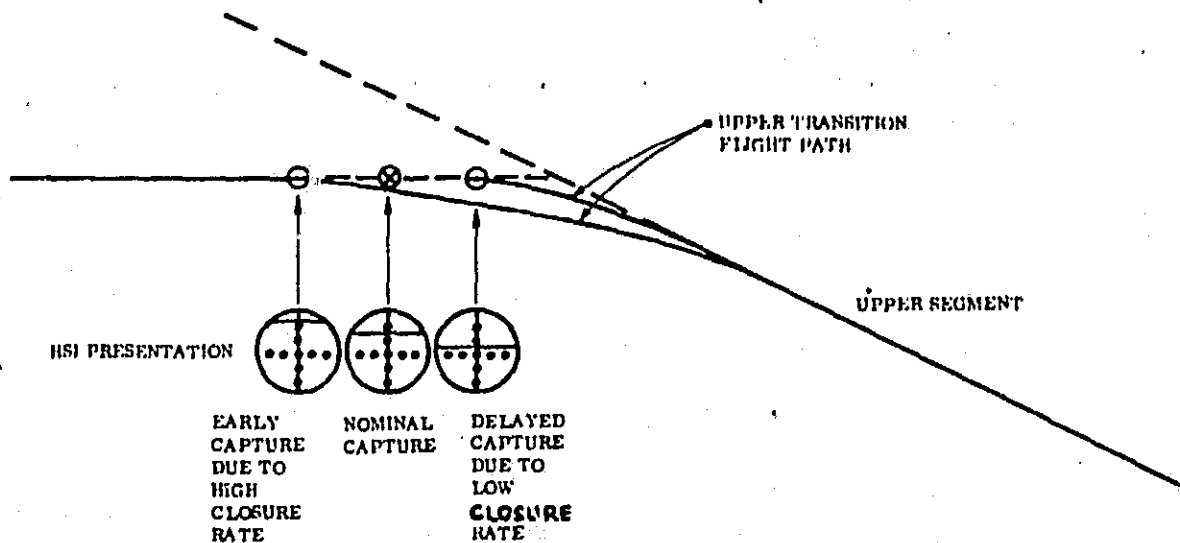
Intercepts to the upper segment can be made with the airplane climbing or descending. The system is designed to capture the upper segment as a function of the closing rate to the upper segment. A high closure rate produced by a climbing intercept will result in capturing the upper segment earlier or with larger HSI deviation. A level flight path to the capture point with 172 KT IAS produced an upper segment capture at 1.9 dots deviation. A climbing flight path of 500/fpm at 170 KTS IAS produced an upper segment capture at 2.2 dots deviation. There was a slight overshoot of the upper segment during the upper transition from a climbing intercept. This was not considered to be significant since the transition rate seemed the same as when making a level intercept, and a climbing intercept for approach is an unlikely operational occurrence. A descending flight path of 1000/fpm at 178 KTS IAS produced an upper segment capture at 0.7 dots deviation.

(b) Upper Transition

The ability of the pilot or autopilot to smoothly track the upper segment is dependent upon the transition from the initial intercept altitude to the upper segment. If the transition is too abrupt, there tends to be a period of

A. 1. (b) Continued

oscillation in the initial tracking and some discomfort to passengers. If the transition is too casual, an overshoot usually occurs resulting in a greater change in altitude before stabilizing on the upper segment. To avoid these problems, the upper capture point is made dependent upon the rate of closure to the upper segment. If the initial airspeed is high, if there is a tailwind, or if the airplane is climbing, then the capture point will occur early. If the initial speed is slow, if there is a headwind or a rate of descent, then the capture point will occur closer to the upper segment.



UPPER CAPTURE VARIATIONS

FIGURE 2

A. 1. (b) Continued

The upper capture point nominally occurs at about 1.8 dots deviation on the HSI instrument when the airplane is stabilized at 160 KTS IAS, level altitude at 3000' MSI, (with airport elevation near sea level) in calm air. The HSI sensitivity is 250' per dot so the capture occurs when the airplane is about 450' below the upper segment. This is not adequate warning for the pilot to anticipate the capture point and the impending transition. Thus the pilot must cross check the DME to have sufficient time to get ready for the descent. If the sensitivity were 500'/dot, the HSI would provide a much better indication to the pilot but then the sensitivity would not be as good on the upper segment as is the 250'/dot.

The upper transition is generally smooth and easy for the pilot or the autopilot to fly. Successful transitions were made with entry speeds as high as 250 KTS IAS. In this instance, there was some noticeable overshoot and subsequent increase in steepness to the initial portion of the descent. Airspeeds of 200 KTS IAS or less were much more desirable and comfortable to the passengers and crew. The best speed for upper capture is 160 KTS IAS.

An unsatisfactory upper transition usually resulted when the airplane was on an intercept heading such that upper capture point occurred prior to localizer capture at an airspeed above 180 KTS IAS. The flight path angle produces a slow closure rate to the upper segment so the upper capture point is close to the upper segment. The turn to align with the localizer occurs during the upper transition, and the transition is shortened resulting in a more abrupt push-over. If this situation should occur, the pilot can slow and configure to 160 KTS or less to make the transition satisfactory.

(c) Upper Segment Angle

The upper segment angle was varied between 5.2° and 7.0°. The practical limits of the angle for the B-727-200 are 5.2° and 6.5°. Angles in excess of 6.5° require the throttles to be closed at all times while flying on the upper segment. Any tailwind then compounds the problem

A. 1. (c) Continued

of stabilizing the airplane and requires the pilot to have engines at idle below 500' AFL. The higher angles do provide noise abatement as they put the airplane higher and at a lower power setting. Angles lower than 5.2° will not produce significant noise improvement. At 5.2° , the airplane can stabilize on the upper segment with full anti-icing capability.

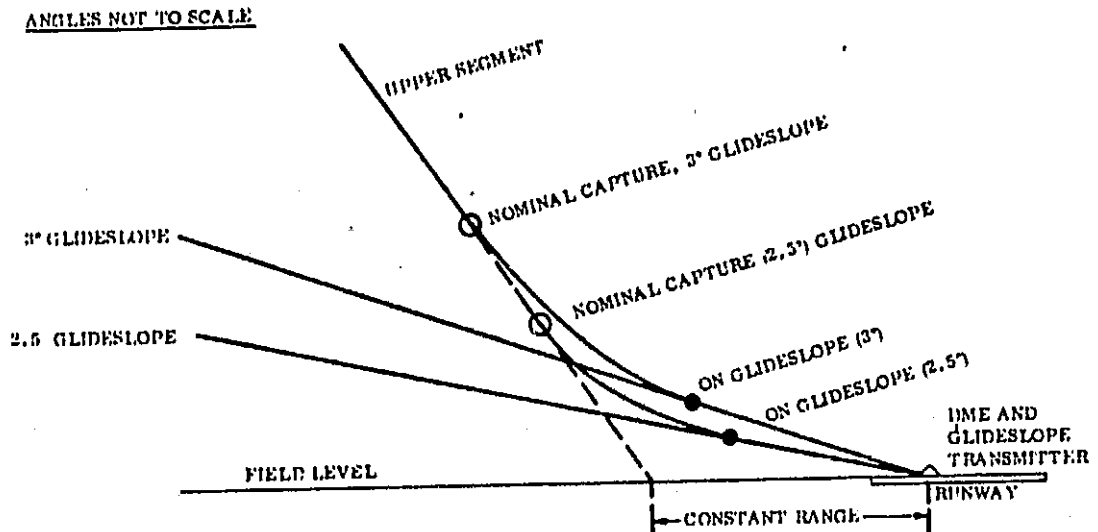
The 6° angle was selected as the best compromise. It provides good noise abatement and can be flown with up to 20 knots direct tail wind at maximum landing gross weights prior to the throttle having to be retarded to idle throughout the upper segment.

(d) Lower Transition

The key to a good two-segment approach is the transition from the upper segment to the glide slope. If the transition is too abrupt, a tendency to undershoot the glide slope exists; if the transition is too slow, then the airplane never quite reaches the glide slope in time for the pilot to feel stabilized.

The lower transition is smooth and easy to fly and very satisfactory from a pilot or passenger point-of-view. The lower capture point shifts as a function of the rate of closure to the glide slope. A high airspeed or tailwind will produce a higher capture point; a low airspeed or headwind will produce a lower capture point. The angle of the glide slope also affects the lower capture point since closure rate on a lower glide slope angle is higher than on a higher glide slope angle. The upper segment path is calculated from the DME and altitude above the field level and is therefore positioned a constant distance from the DME transmitter. If the glide slope is shallow (2.5°), it intersects the upper segment at a lower altitude than if the glide slope were steep (3.0°). The resulting lower capture points are adjusted by this altitude difference and the airplane arrives on the glide slope beam at a lower altitude. The upper segment was positioned far enough out to accommodate the lowest glide slope expected to be flown (2.5°) (ref. Figure 3).

A. 1. (d) Continued



LOWER CAPTURE VARIATIONS

FIGURE 3

The lower transition requires from 20 to 30 seconds and 250 to 500' of altitude to transition the airplane from the upper segment to the glide slope. The pitch rate varies with the conditions of transition. All transitions feel about the same to the pilot, and are virtually imperceptible to the passengers.

A. 1. (e) Lower Intersect Altitude

The evaluation of the lower intersect altitude was conducted primarily during the ground noise measurement approaches. It was desired to get the intersection of the upper segment and the glide slope as low as possible because the closer to the runway the upper segment is, the higher above the ground at any given point the airplane is, and the better the noise abatement. The lower intersect altitude was evaluated at 1000', 690', and 500'. The 500' intersect altitude had the best noise reduction but allowed the airplane to reach about 200' AFL before stabilizing on the glide slope. The project pilots had no difficulty flying the approach this low but expressed concern about doing so routinely. The project pilots were also concerned about the accuracy of the system and would want guarantees and more experience with the equipment before operating IFR with a low intersect altitude. The 690' intersect altitude provided significant noise improvement and is high enough to allow the airplane to complete the lower transition and stabilize on the glide slope above 500' AFL, the minimum operationally acceptable stabilization altitude.

(f) Glide Slope

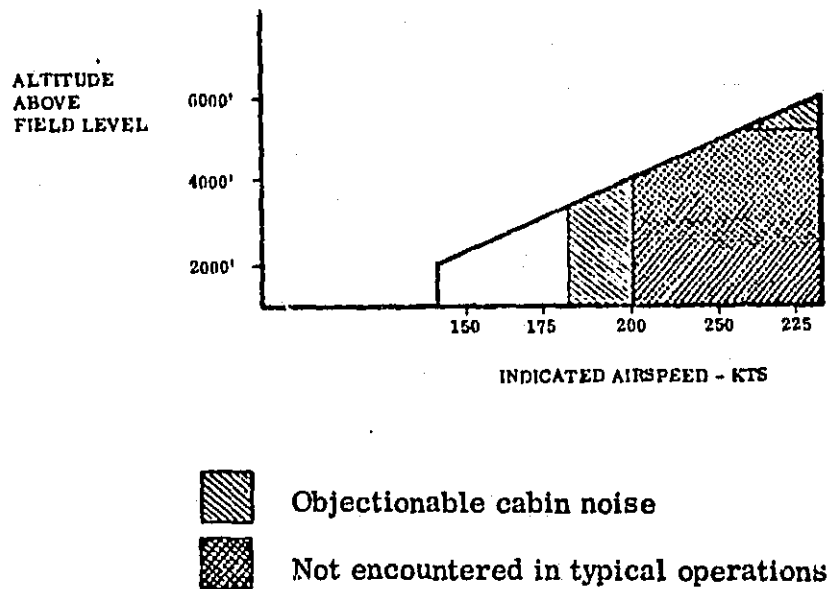
The glide slope variation occurred as a result of the various glide slope angles on different runways. The glide slope variation did not affect the ease of flying the two-segment approach although the shallower glide slopes require greater flight path angle change and therefore greater attitude change than steeper glide slopes.

2. Airspeed Schedule Variations

The airspeed schedule was varied through a wide range of values. These variations did not produce any significant differences in the approach. The best results in maintaining the desired airspeed were obtained when the airspeed schedule (speed vs. distance from touchdown) was the same as flown during the standard ILS.

A. 2. Continued

Experience in the airplane definitely indicated that, both from the passenger comfort and pilot workload standpoints, the smaller the difference between the entry speed and the upper segment target speed, the more desirable was the approach.



UPPER SEGMENT CAPTURE AIRSPEED ENVELOPE

FIGURE 4

Figure 4 above shows the relationship between the entry airspeed and altitude above the field using as the basic criterion: the airplane must be stabilized at final speed in landing configuration by 500 feet above the field. The shaded area shows the objectionable cabin noise level resulting from lowering the landing gear at airspeeds in excess of 180 knots. ATC does not commonly request airspeeds in excess of 200 knots for aircraft in the approach environment between 3000 and 5000 feet above the field. The majority of the intercepts were accomplished at 180 knots or less.

A. 2. Continued

The ideal speed for upper segment intercept is the same speed as the upper segment is to be flown. There is usually a moderate power reduction to make during the upper transition, and no pitch trimming is required. However, this approach speed is very impractical from a traffic control point-of-view. In most heavy traffic situations, ATC required 160 to 180 knots to the outer marker. These speeds were easy to accommodate even when the upper capture and transition was made miles outside the outer marker. The airplane could be stabilized at 180 KTS on the upper segment from 5000 to 3000' and then slowed and restabilized at a lower speed from 3000' (outer marker) on down. Higher airspeeds required the throttles to remain at idle on the upper segment longer than most pilots like. If the airspeed at 3000' AGL upper capture is above 190 KTS, then the throttles would have to remain at idle down into the lower transition. This situation is not satisfactory for an IFR approach and is marginal during a VFR approach. The approach was not considered operationally satisfactory if the throttles were not up and the engine RPM stabilized prior to the lower capture point.

Two airspeed schedules were found to be acceptable for the approach. The pilot could add a 10 knot airspeed increment to the upper segment portion of the approach and bleed it off during the lower transition, or he could maintain the normal final approach airspeed throughout the entire profile from upper segment to the runway threshold. In the first case, the pilot must make a trim change during the lower transition and add a small amount of power. In the second case, the pilot must add more power and pay closer attention to the airspeed as it must be held constant. In both cases, it required three or four approaches before the pilot became familiar with the technique of adding power in the correct amount at the correct time. This latter schedule (constant speed) provided the best results overall.

In all cases, it requires more attention on the pilot's part to maintain the desired airspeed during and after the lower transition than during a standard approach since the pilot does not have as long to establish the airspeed on the glide slope. Airspeed control on the upper segment is easier to maintain than on the glide slope.

A. 2. Continued

Approaches were made where the airspeed was kept low on the upper segment and then increased on the glide slope. The power changes necessary to do this defeat the concept of noise abatement and the effort required is an increase in workload for the pilot. Approaches were also made where an airspeed increment as large as 40 KTS was maintained on the upper segment and bled off during the lower transition and on the glide slope. Any increment over 10 KTS delayed getting the power stabilized on the lower segment. The 40 knot increment required that the throttles be at idle to 200' AFL, which is unacceptable. It was also noticed that when 15 knots or more were bled off during the lower transition, the airplane would sink slightly through the glide slope during the transition. The pilots were about evenly divided on whether to carry the 10 knot increment or fly at constant speed. They were unanimous in determining that it requires more attention to airspeed during and after the lower transition.

3. Configuration Schedule Variations

Many configuration schedules were attempted during the Engineering Evaluation. Most of these resulted in an increase in pilot workload. The best results were obtained when the landing gear was extended during the upper transition and the flaps set to their final setting (30° or 40°) shortly thereafter. The 30° flap schedule is recommended as it results in a lower thrust setting and is therefore better from a noise abatement standpoint. In instances where a tailwind was encountered with a 30° flap schedule and a low power setting, the pilot could get improvement by selecting 40° flaps. Delaying the gear extension resulted in idle power too long. Delaying the flaps compounded the problem in that the airspeed would not stabilize even with the throttles at idle. Several approaches were made using a delayed flap technique, changing from 30° to 40° flaps and changing from 40° to 30° flaps. Each of these routines caused an increase to the pilot workload by causing increased trim and airspeed management and did not contribute significantly to noise improvement.

A. 3. Continued

The standard procedure is to configure the airplane progressively and establish the final flap setting and stabilization of the approach well above the ground. Therefore, the technique to program to the final flap setting on the upper segment and stabilize the two-segment approach is consistent with present technique and procedure.

4. Raw Data Presentation

An approach was made with the two-segment switch armed, and all approach requirements met except the flight director and autopilot were off. The upper segment appeared on the HSI and a transition was manually made using the HSI deviation as a guide. The upper segment was followed down to the glide slope with small pitch corrections as small deviations were noticed. At one-half dot deviation above the glide slope, the HSI vertical deviation bar flag appeared and remained. The glide slope deviation on the ADI was followed to the threshold. The HSI deviation continued displaying upper segment raw data but it remained flagged.

5. Safety Protectors

There are three lower intercept safety protectors that will disengage the two-segment system: (1) if, within 5 NM of touch down, the aircraft comes within one-half dot of the glide slope and it is not captured; (2) if the DME becomes 1.8 NM or less and the glide slope is not captured; and (3) if the altitude above field elevation becomes 500' or less and the glide slope is not captured. To test these safety protectors, it was necessary to disable the two not being tested. On one approach, the 1.8 DME, the 500' above field level and the glide slope capture functions were disabled; when the airplane flew within one-half dot above the glide slope (the DME was 2.2 and the altitude 635' AFL), the autopilot disengaged, the flight director fly bar retracted out of view, and the steer flag came into view. On another approach glide slope capture, the 500' and the one-half dot protectors were disabled. The Airport Elevation Panel was also set 200' high to move the upper segment in closer to the runway. The system tripped at 1.8 DME.

A. 5. Continued

On a third approach, the glide slope capture, the 1.8 DME, and the one-half dot protectors were disabled. The Airport Elevation Panel was set 100' high to keep the airplane above the glide slope. This time the system tripped when the baro altitude was 530' MSL (which is 500' AFL at Stockton). Thus each of the safety protectors are functional and the warning they produce is adequate.

6. Two-Segment Instrument Presentation

The consensus of the Project Pilots and other pilots who flew pilot evaluations during some of the Engineering Evaluation was that the two-segment approach system presentation is satisfactory and clearly indicates to the pilot the mode of operation and that it is a viable system for routine airline operation. The two-segment switch is well located. The Approach Progress Display is very good in its position and clarity. The Airport Elevation Panel is well placed, easy to read, and gives the pilot a reference for his MSL altitude at touchdown. The presentation fits the routine operation of the airplane with a few minor changes in normal procedures.

7. Co-Pilot Instrumentation Presentation

There has been no interference from the two-segment system. The Co-pilot instrumentation is unmodified and indicates the standard ILS only. If the flight director is armed for auto approach on the initial approach, it will stay armed until the airplane transitions onto the glide slope. At this point, the flight director will capture the glide slope (at about 500' AFL) and from that point on, the Captain's and Co-pilot's flight directors command the same flight path. The glide slope deviation indicator on the ADI's always indicate the same. The HSI deviation indicators will be the same from glide slope capture on in, as the Captain's HSI switches from upper segment to glide slope information at that point. The Co-pilot's instrumentation is essentially identical to the Captain's from 500' AFL down to touchdown and provides an excellent safety monitor of the approach from that point.

A. 4. Weather Effects

Throughout the Engineering Evaluation various degrees of weather were encountered. In these instances, special notice was made in order to verify the two-segment approach operation during these actual weather conditions.

(a) Low Visibility

Low visibility did not present any increase in difficulty to the pilot. If visual contact with the runway was established prior to the lower transition, the pilot would continue on following his guidance, either autopilot or flight director, through the transition and onto the glide slope. If visual contact with the runway was established after the lower transition, then it is no different than a standard ILS. Lack of visual contact at minimums is no different than when flying a standard ILS.

(b) Lighting

Many night flights were conducted and the lighting of the two-segment system was determined to be identical to the lighting of the standard ILS system. If visual contact is established at the outer marker (3000' AFL) during dark night operations, the two-segment approach offers a better view of the airport and the surrounding area than does the lower standard ILS. The increased altitude does not, however, increase the angle to the runway so much that it looks to the pilot like he is diving into a deep hole. The upper segment, lower transition, and glide slope tracking are no different than during daylight operations.

(c) Winds

The wind effect on a two-segment approach is very similar to the standard ILS. The flight director and autopilot are capable of compensating for head, cross and tail winds to the same extent as when flying a standard ILS. The actual wind at the exact time of an approach was difficult to determine. In most instances, a wind reading at the runway was obtained from the airport tower just prior to the approach. The winds aloft were taken from the latest area wind reports.

A. 8. (c) Continued

The only difficulty with the two-segment approach appeared on the upper segment when the tailwinds were greater than approximately 20 knots. The throttles were retarded to idle at the upper capture point and stayed there until the airplane was well into the lower transition under these conditions. The use of 40° flaps instead of 30° improves the situation by permitting the throttles to be forward of the idle position with a 20 knot tailwind. The crosswinds encountered during the evaluation required up to 12° heading correction to hold the center line of the localizer. Standard ILS approaches required the same correction.

(d) Turbulence

Turbulent flight conditions from moderate to severe were encountered while flying approaches at Reno. It was very apparent that the turbulence had less effect on the ability of the pilot to fly precisely on the upper segment than on the glide slope. The autopilot and flight director are able to hold the airplane to much smaller deviations while on the upper segment than when tracking a standard ILS. The lower transition and glide slope tracking was the same as a standard ILS with all degrees of tracking. The overall comparison of the effect of turbulence on a two-segment versus the effect on a standard ILS shows the two-segment approach is better. The pilot must work as hard while flying the lower transition and glide slope as he does when flying a standard ILS. He gets some relief on the upper segment as it is easier to fly in turbulence than is the section of the glide slope that lies beneath the upper segment since the upper segment reduces the period of time the pilot is forced into an accelerated workload.

9. Gross Weight and Center of Gravity Effects

The two-segment approach was flown with the gross weight up to the maximum landing limit (160,000 lbs). The center of gravity was varied between the aft limit (34% MAC) and 20% MAC. The effect of C. G. and gross weight changes on the two-segment approach appear to be the same as these effects on the standard ILS approach.

A. Continued

10. Emergency and Irregularities

The two-segment approach system installation and operation does not require any change in any emergency or irregularity procedure published in the Approved Flight Manual. If an emergency or irregularity should occur while flying the two-segment approach, the pilot has every option open to him that he does during the standard ILS. The two-segment approach is a problem to fly if the abnormal situation requires an approach configuration of less than 30° flaps. The 6° glide slope requires the drag of the landing gear and at least 30° flaps in order to stabilize at proper approach speeds with other than idle thrust. The two-segment approach easily accommodates the two-engine approach. The other irregular approaches (manual flight control, no-flap, one engine, etc.) require additional investigation. This evaluation was for normal line service and did not include in depth investigation into these types of emergencies and irregularities.

11. Pilot Workload

The increase or decrease in pilot workload is an important element of the two-segment approach evaluation. The increase in workload due to switches and procedures is relatively easy to determine. The two-segment approach procedure adds several items to the ILS procedure: the two-segment switch, the upper segment annunciation in the approach progress display, the DME switch, and the airport elevation panel.

The two-segment switch is a decision switch: if the pilot elects to make a two-segment approach, he sets this switch to ARM and the approach system shifts from a standard ILS to a two-segment ILS. Therefore, this switch is not on a checklist and does not represent any increase in procedure workload.

The upper segment annunciation light keeps the pilot apprised as to the capture of the upper segment, and its position between the localizer light and the glide slope light is natural and insignificant in its effect on workload.

The DME switch must be on in order for the two-segment computer to calculate the upper segment. If the switch is

A. 11. Continued

off and the two-segment switch selected, the HSI vertical deviation would be flagged, the flight director fly bar would be retracted, and the steer flag in view. Turning the DME switch on remedies this situation. The pilot must have a knowledge of the system to the extent that he can quickly check every item necessary to validate the two-segment approach if the Upper Segment Arm (amber) light does not come on when the two-segment switch is selected to ARM. This attention adds workload to the pilot. With sufficient experience, it is easily accommodated.

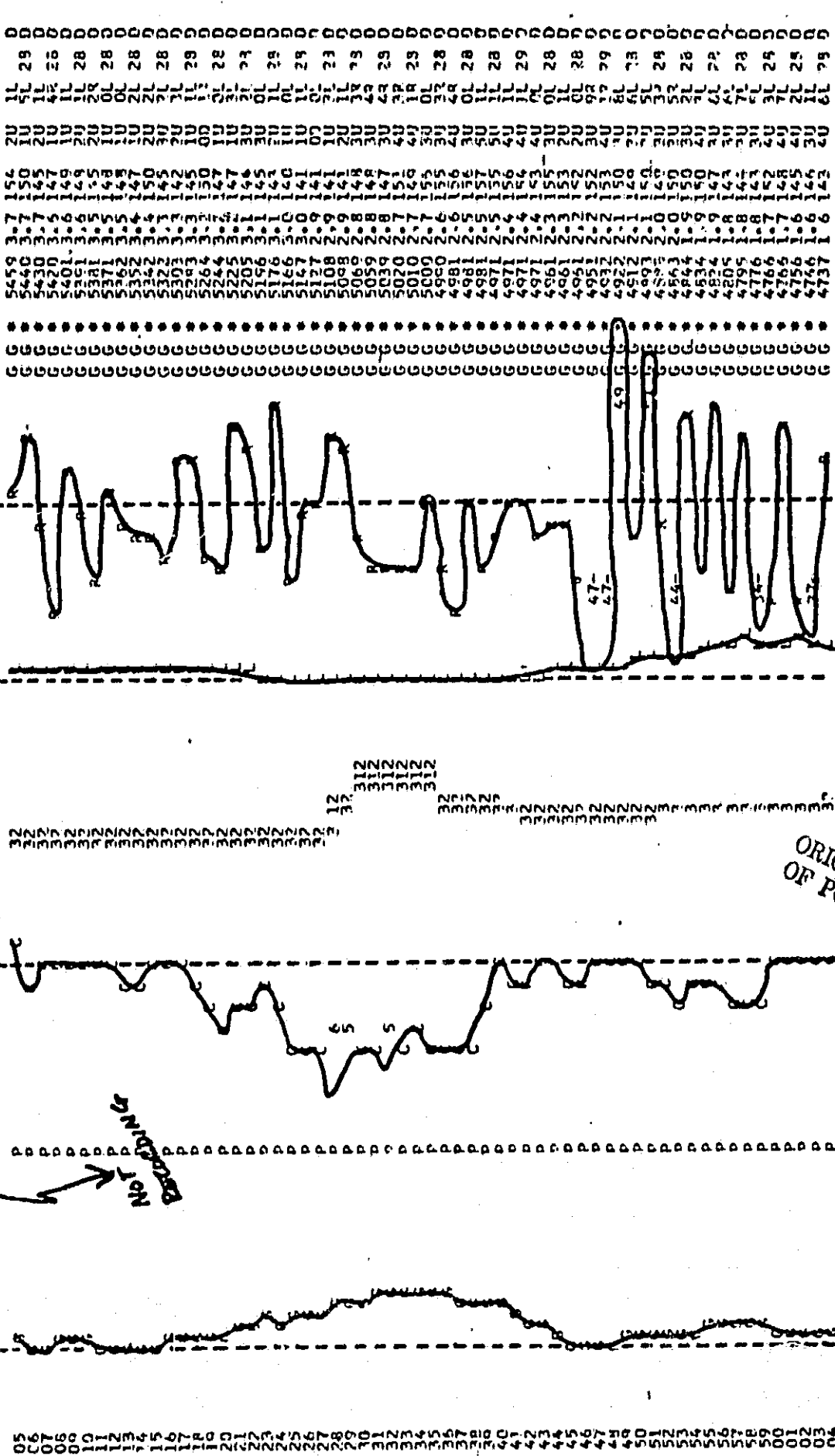
The airport elevation panel must be set correctly as must the baro-altimeter. The baro-altimeter is set as a routine procedure and checked by the approach descent check list. The airplane elevation panel setting can be set at the same time and also checked by an added item to the approach descent check list. This setting is an insignificant workload increase. The procedural increase in pilot workload is not a significant factor in the two-segment approach system operation.

The increase or decrease in pilot workload due to a change in flight technique involved in the two-segment approach is much more difficult to determine. An observer can evaluate the pilot's performance and rate the relative results of two approaches but he cannot determine exactly how much effort goes into each. In the course of the Engineering Flight Evaluation, the pilots were asked to compare workload between the standard ILS and the two-segment ILS. Every attempt was made to have the two approaches as close together as possible so the same flight conditions prevailed on each approach. Only the pilot himself can determine which requires the most work although some of the digital data can assist in this assessment.

Plot 1, flown on January 29, 1973, at Reno ILS 16, is a standard flight director ILS approach. Plot 2, flown on the same date, was a two-segment flight director approach that followed closely. The standard ILS was at 3.7 NM at 10:25 and 5 seconds and the two-segment thirteen minutes later at 10:38 and 25 seconds. The winds aloft were out of the west. The runway winds reported at 180°/25 knots. There was moderate to heavy turbulence. The pilot's comment in comparing the two approaches was that the two-segment approach (Plot 2) was easier to fly than was the standard

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 RUN TIME 13.36
 TIME 10.25
 NASA/UAL TWO SEGMENT NOISE ABATEMENT APPROACH TEST - OPERATIONAL EVALUATION
 FLIGHT DATE 01/29/73 APPROACH NO 001 RENO, NEVADA RUNWAY 16 GROSS WT 152,000 LBS CREW 00029/05020
 APPROACH TYPE FLIGHTDIR
 UPPER SEGM ANGLE 6.0 GLIDESLOPE INTERCEPT 690 GLIDESLOPE BIAS .0 DOTS

GLIDESLOPEX<--PITCH CONTROL-->X<--THROTTLES-->LOCALIZER<--ROLL CONTROL-->ANNUNC ALT DME IAS ATTIT TE L E
 UP: 100% DNUP DNUP DEGREES DN X10 PERCENT LT 100% RLT DEGREES RT FD AP AFL .1 KTS PIT ROL FL G V
 SE: 186420246816 5 4 3 2 1 0 1 2 3 4 3 2 1 0 1 2 0-1-2-3-4-5-6-718647024581074185296303692581470 UGLUGS FEET NM



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A. 11. Continued

ILS, and that the wind shear and the turbulence was easier to handle.

The observer comment was that the pilot did a better job of following the two-segment flight path than he did following the standard ILS flight path. An examination of the printed data "Operational Evaluation" verified these comments. The pilot took 60 seconds to go from 3.7 NM to 1.6 NM on the standard ILS and only 52 seconds on the two-segment during which the lower transition was executed. (From the column "ALT AFL FEET" on Plot 1, it can be seen that the airport elevation panel was not set since it is not necessary on a standard ILS.) Both approaches were flown at about the same speed. On the standard ILS, the pilot got a dot low on the glide slope and also slow on his airspeed, requiring a large pitch correction as being commanded in column "PITCH COM" and a large throttle change as shown in column "THROTTLES." Comparing column "LOCALIZER" indicates a slightly better job of keeping the deviation small on Plot 2. Column "ROLL CHANNEL" shows a lot more aileron activity in Plot 1 than Plot 2. Column "PITCH COM" indicates smaller command positions on the flight director fly bar on Plot 2 than Plot 1. Thus this printed data shows a good relationship to the pilot and observer comments as to the relative workload of each approach.

Plot 3 and 4, flown February 5, 1973, are successive flight director standard ILS and two-segment approaches. The flight conditions were clear, smooth, and calm winds. The pilot comment was that the standard ILS was easier to fly than was the two-segment. The observer comment was that the pilot flew an outstanding ILS. On the two-segment approach, he did not track the glide slope close enough following the lower transition but it was still a good approach. Examining the printed data of Plot 3 and 4 shows very little difference in the activity of the two approaches. The roll control activity is less on the standard ILS. The power is also set such that it does not require any adjustment, whereas in Plot 4 a small power increment is needed at the lower transition. There is also slightly more pitch command error on Plot 4. Each of these items indicate that slightly more attention is required to fly a good two-segment ILS than is needed to fly a standard ILS. It is significant that the difference here is largely due to weather conditions. The two-segment approach was not much more difficult.

A. 11. Continued

The third set, Plot 5 and 6, flown on February 8, 1973, had smooth air and weather right at minimums. In such conditions, the pilot naturally works much harder than the pilot of Plot 3 and 4. The pilot comment here was that he did not see any appreciable difference in the two approaches. Examining the printed data shows Plot 6 (two-segment) with some increase in roll activity over Plot 5, but the increase in activity is not significant. Comparison of Plots 5 and 6 with Plots 3 and 4 indicates that when a pilot has to work harder to fly a good standard ILS due to weather conditions, he also must work harder to fly a good two-segment ILS.

These examples are typical of the experience of the two-segment evaluation. In general, the flight technique for the two-segment approach requires more attention on the part of the pilot, especially following the lower transition, than does the standard ILS. As the flight conditions, turbulence, and visibility become worse, the difference in the pilot workload becomes smaller. This characteristic of the two-segment approach system lends itself very well to routine airline operation.

12. Fuel Savings

During the Engineering Evaluation of the two-segment approach, it became apparent that the airplane was using less fuel from turn in to low approach than it was during a standard approach. Flight tests show that a 727-222 airplane at 132,000 lbs. gross weight, 160 KTS IAS standard day, 5° flaps, flying level at 4000' MSL, has a fuel flow of 3150 lbs per hour per engine, travels the 4 NM distance (10 NM to 6 NM) leading to the upper segment in 1.39 minutes, burning 219 lbs. of fuel. The same airplane approach at 2000' MSL travels the 4 NM in 1.44 minutes with a fuel flow of 3200 lbs. per hour per engine and burns 230 lbs. of fuel. The distance from the upper capture point to 2 NM is flown at 135 KTS IAS 30° flaps, gear down and an average fuel flow of 1800 lbs. per hour per engine. The distance covered in 1.45 minutes, using 130 lbs. of fuel. A standard ILS from 6 NM to 2 NM uses 3500 lbs. per hour per engine, 1.46 minutes and 256 lbs. fuel used. Adding these data, the standard ILS from 10 NM to 2 NM uses 486 lbs., and the two-segment approach uses 349 lbs.; that is a difference of 137 lbs. per approach. Since the two-segment approach is higher than the standard approach at 10 NM, actual savings per approach are somewhat less than this given common initial conditions. Due to increased interest in fuel conservation, more rigorous testing of the benefits of two-segment approaches in this area is advised.

PAGE 3

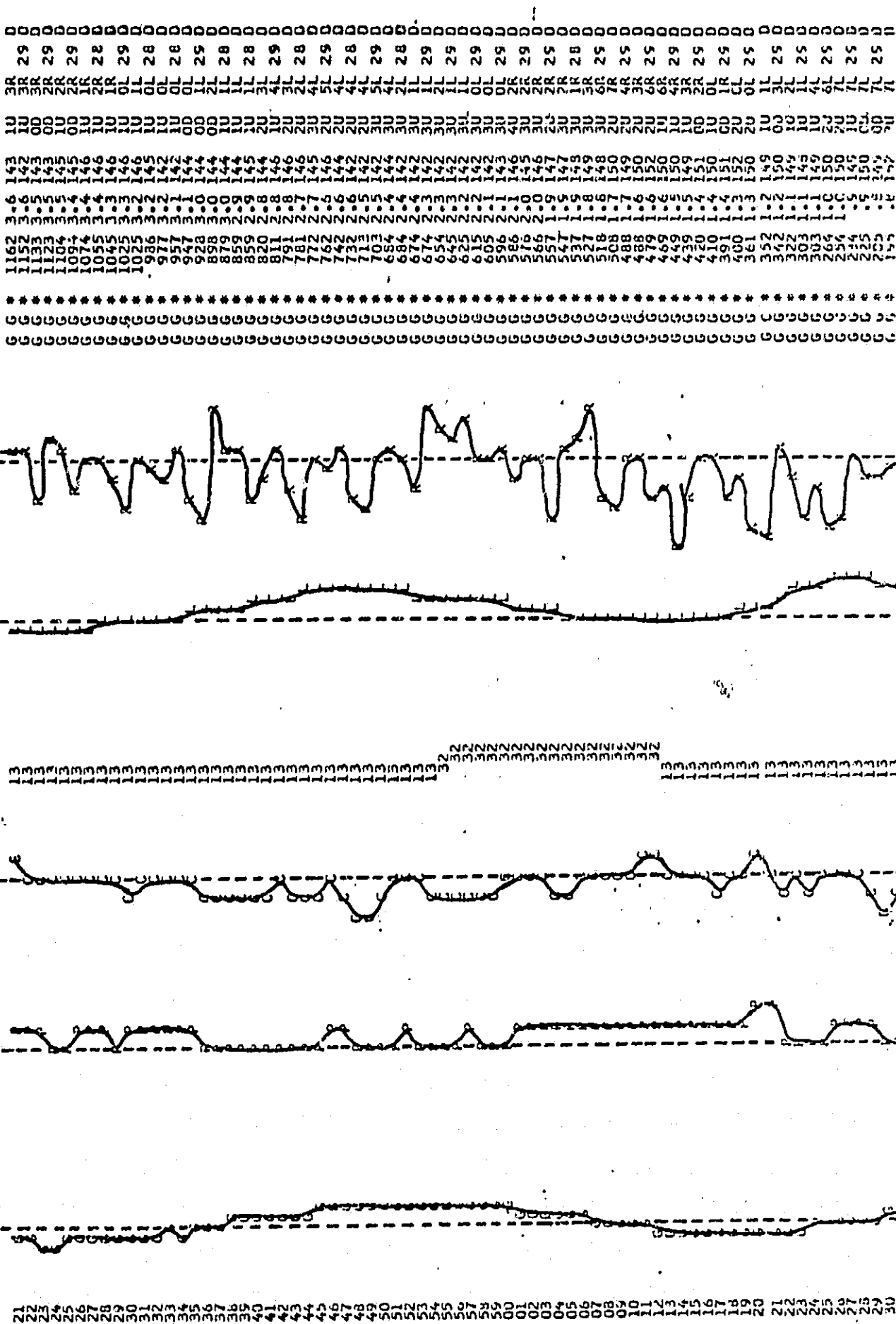
NASA/UAL TWO SEGMENT NOISE ABATEMENT APPROACH TEST - OPERATIONAL EVALUATION

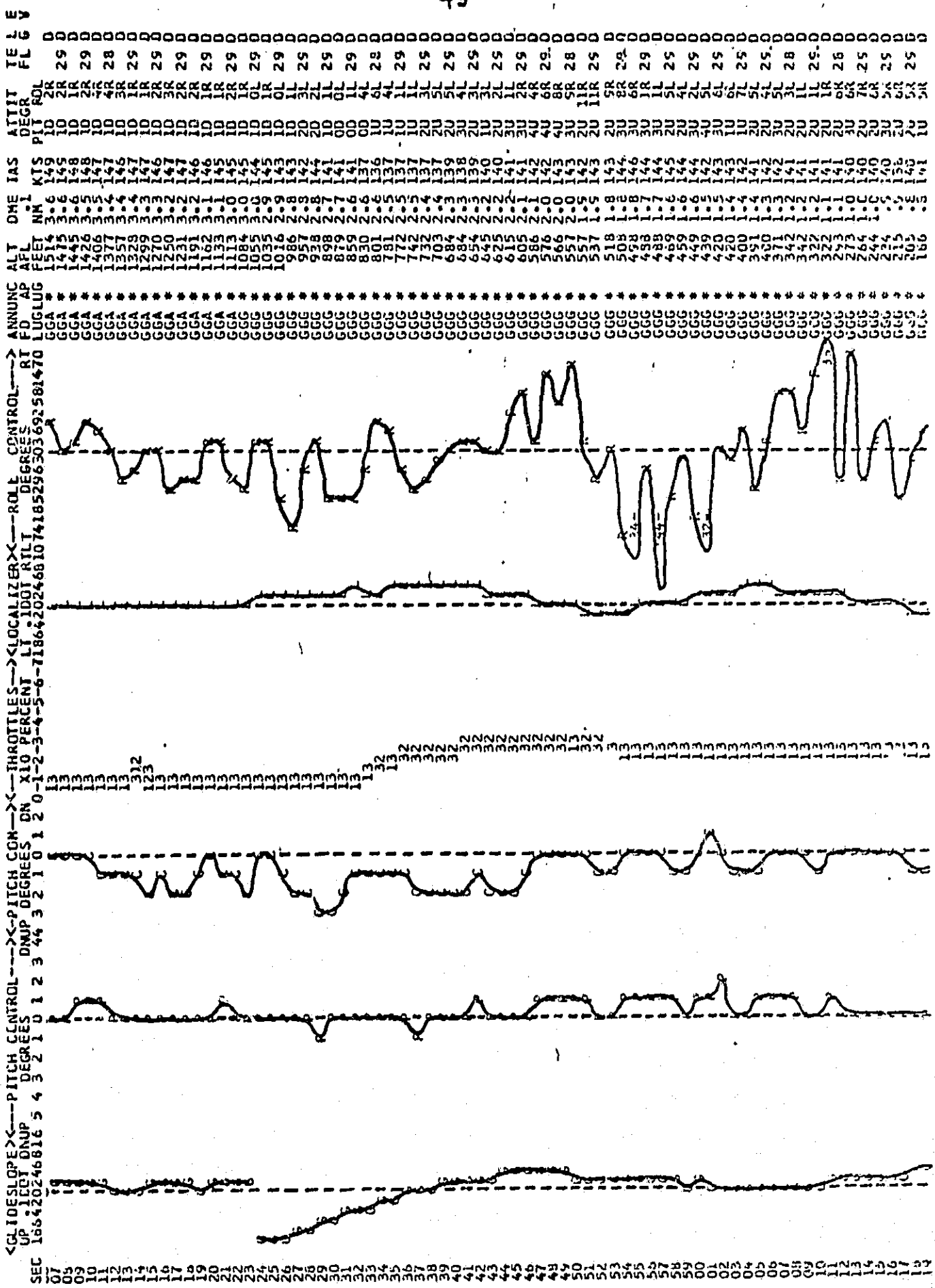
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RUN TIME 20:27

FLIGHT DATE 02/08/73 APPROACH NO 001 STOCKTON, CAL RUNWAY 29R GROSS WT 154,500 LBS CREW 00047/21631

TIME 09.15

APPROACH TYPE UPPER SEGMENT ANGLE .0 GLIDESLOPE INTERCEPT 0 GLIDESLOPE BIAS .0 DOTS

GLIDESLOPE>>>PITCH CONTROL<<<PITCH COM-->>>THROTTLES--><LOCALIZER--><ROLL CONTROL--><ANUNC ALT DME IAS ATTTT TE L E
UP : LGT LNUP DEGREES ON X10 PERCENT LT 1001 RLT DEGREES RT FD AP AFL .1 DEGR FL G V
SEC 150420240816 5 4 3 2 1 0 1 2 3 4 4 3 2 1 0 1 2 0-1-2-3-4-5-6-718642024081074185296303692581470 LUGLUG FEET NM KTS PIT ROL



Plot 6.

B. Abnormal Operations

Extensive investigation of the effects of abnormal operation and component failures on the two-segment approach system were made. The results of the investigation into the areas listed below are reported in this section.

1. Missed Altitude Functions
2. Response to a False Glide Slope Lobe
3. Inadvertent Operation of the Two-Segment Switch while on a Standard ILS
4. Following the Two-Segment Guidance Without Localizer or Glide Slope
5. Upper Intercept Altitude Limits
6. Airspeed Schedule Limits
7. Gross Weight and C. G. Limits
8. Engine-out Two-Segment Approach
9. Component Failures:
 - (a) DME
 - (b) Air Data Computer
 - (c) Two-Segment Computer
 - (d) Glide Slope
 - (e) Localizer
 - (f) Switching Unit Failure
 - (g) Safety Protectors Failure

B. 1. Misset Altitude Functions

Two-segment approaches were made for evaluation of missetting the barometric correction on the barometric altimeter and missetting the touchdown zone value in the Field Elevation Panel. These errors have the same effect in that the position of the upper segment relative to the runway is shifted. These errors simulate several types of equipment failures as well as operational abnormalities such as flying from Reno to San Francisco without re-setting the field elevation.

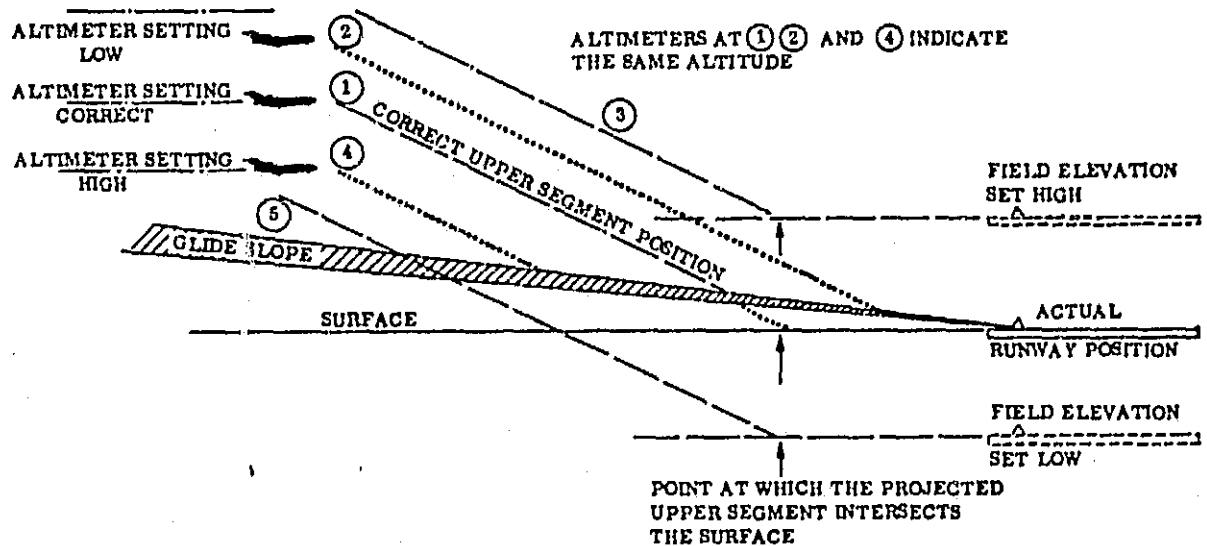


FIGURE 5

Figure 5 shows how the upper segment path shifts due to altimeter errors and field elevation errors. If the field elevation panel is set high, the calculations made using DME range and altitude above touchdown zone would move the upper segment up to position 3. The airplane would move forward and descend closer to the runway and would intercept the glide slope at a lower altitude. If the altimeter is set low, the airplane would be at position 2 and start descending at the same DME. Thus when it descends the

B. 1. Continued

amount of the altitude error, it would again be closer to the runway and intercept the glide slope at a lower altitude.

The converse is true when the Field Elevation Panel is set low or the altimeter is set high. The upper segment is shifted away from the runway causing the airplane to start down sooner and intercept the glide slope at a higher altitude. If the errors are large enough, the airplane could capture the upper segment far enough away from the runway to still be below the ILS glide slope. Within ten seconds of upper segment capture the autopilot would disengage, the flight director fly bar retract out of view, and the steer flag would be displayed.

A two-segment autocoupled approach was initiated at Reno with the Airport Elevation Panel misset 4000' low. This resulted in the upper segment angle being positioned farther from the runway. The upper segment was captured at 9000' MSL and 16 NM DME. This produced a capture point below the standard glide slope. The system disengaged the autopilot, the flight director fly bars retracted out of view, and displayed the steer flag. The resulting trip occurred within ten seconds and the pitch change was insignificant. The airport elevation panel was reset to 1000' low and the two-segment system rearmed for capture. With this 1000' misset, the upper segment again is positioned farther from the runway than normal, but above the standard glide slope. The capture occurred normally and transition to the upper segment was smooth. The glide slope was reached before the glide slope arm point (5 NM). Within ten seconds after passing the glide slope, the system again disengaged. Recovery to the standard glide slope was made with normal maneuvering and the airplane did not exceed 3/4 dot below the glide slope. Additional discussion on these errors is in Appendix II.

2. Response to a False Glide Slope Lobe

An evaluation of the response of the two-segment system to a false glide slope lobe was made at Reno. The airplane was stabilized inbound at 9000' on the localizer. The two-segment switch was in "ARM" and the flight director mode selector in "AUTO APPROACH." The autopilot was engaged and its mode selector in "LOCALIZER." The approach progress display (APD) lights of the flight director indicated VOR/LOC

B. 2. Continued

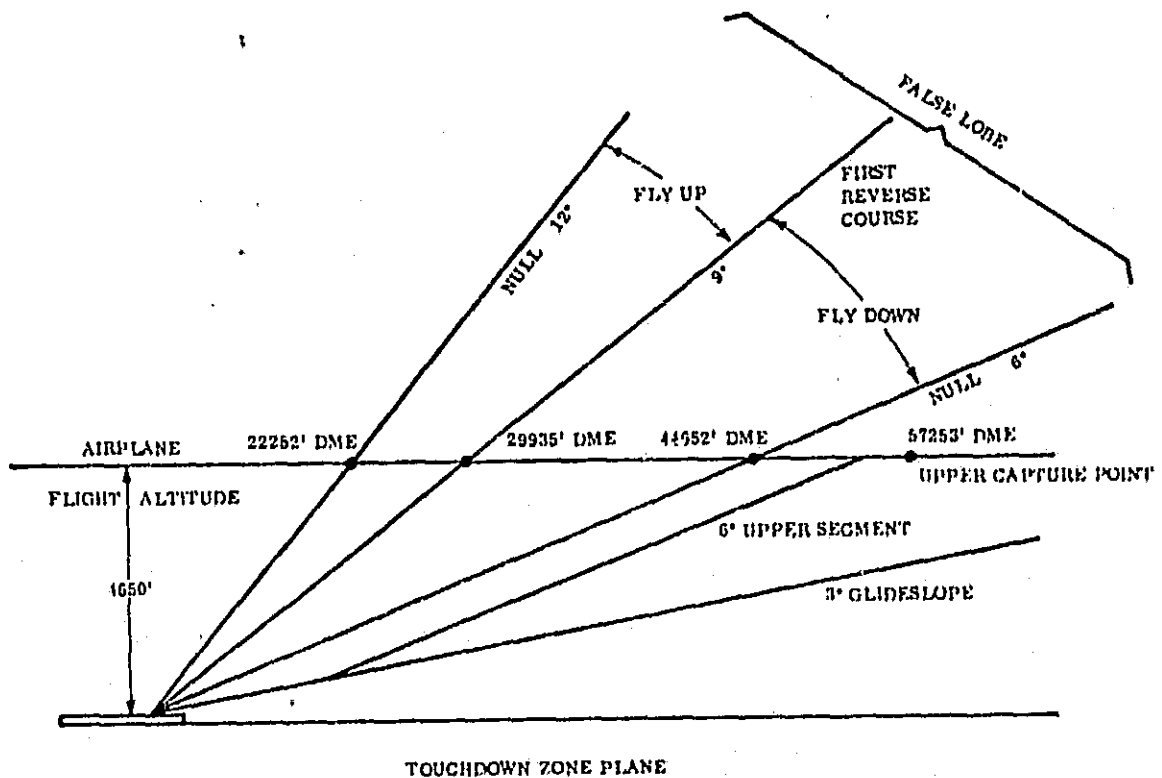
"GREEN" and UPPER SEGMENT "AMBER." The autopilot lights had VOR/LOC "GREEN" only. When the airplane reached the upper segment capture point, the flight director upper segment light turned "GREEN" and the fly bar indicated nose down to transition to the upper segment. The airplane continued straight and level on the localizer as the autopilot received no pitch down command since it was not in "AUTO" approach. The glide slope deviation indicator on the ADI displayed full scale down. The upper segment deviation indicator on the HSI displayed the upper segment two and one-half dots high and moving down. When the HSI deviation was one dot down, the autopilot mode selector was turned to "AUTO APPROACH" and the flight director mode selector was recycled. The autopilot approach progress display lights indicated VOR/LOC "GREEN" and upper segment "AMBER." The HSI deviation indicator progressed down to full off-scale showing the airplane was passing through the upper segment. The autopilot upper segment light remained amber and the airplane continued to track altitude hold since it had passed the upper capture point. Thus the system functioned as designed. Previously it was determined that should the system be armed beyond the capture point for the upper segment, and capture be possible, an undesirable nose down pitching moment might occur. To prevent any such pitch down, the system was designed to require full arming prior to the upper segment capture point.

At about 7.5 NM where the 6° ILS glide slope null intersects the flight altitude, nothing happened: no change in the flight path, the HSI deviation continued down to off scale, and no change in the lights. At the 5 NM DME point where the glide slope light would normally come on amber, there was no change in the lights. At this point, the HSI moved rapidly up to two dots high and then moved full up off-scale then came back down in through center to full scale down. This is where the 9° first reverse course intersects the flight altitude.

At 3.5 DME or where the 12° null intersects the flight altitude, the APD lights remained the same. The flight path did not change, the HSI deviation was moving up and down as though it were responding to the false glide slope signal. The flight path was continued over the runway where the DME reading became about 1 NM without any change in the

B. 2. Continued

APD or flight path. The HSI deviation did indicate full scale up and down deviations as each successive lobe was flown through. The system functioned as designed. There was no adverse response to glide slope false lobes.



FALSE LOBE FLY THROUGH

RENO ILS 16 4/20/73

FIGURE 6

P. Continued

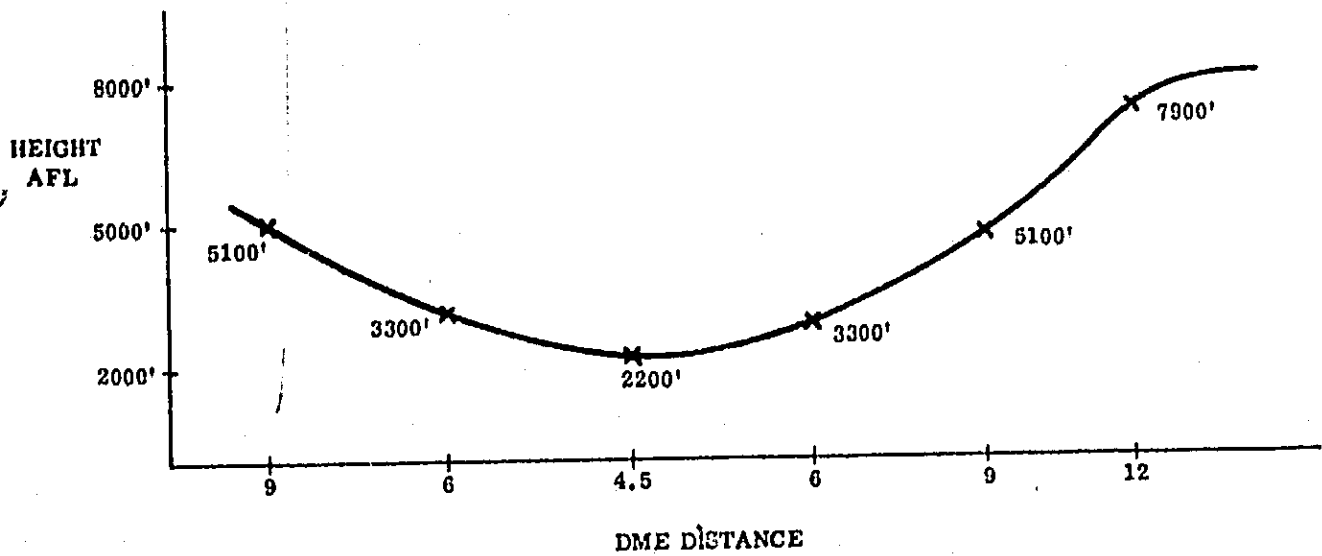
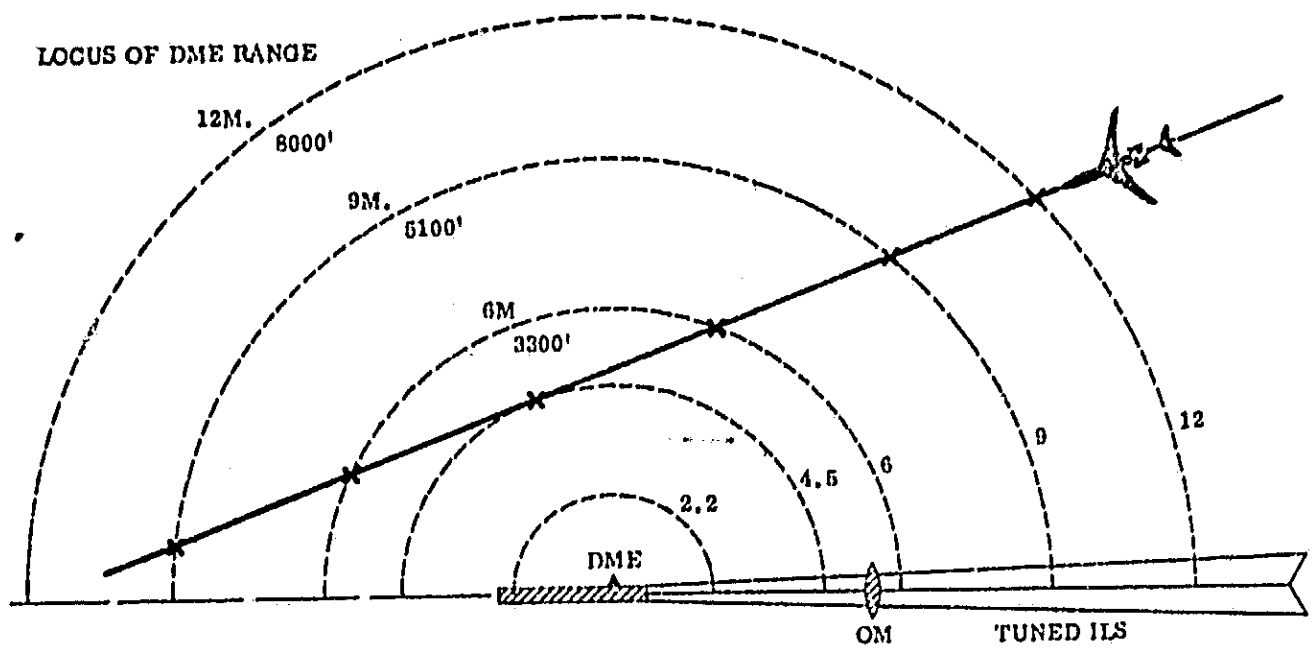
3. Inadvertent Operation of the Two-Segment Switch While on a Standard ILS

The standard ILS glide slope was captured and tracked by the autopilot with flight director following from 3000' down to 2100'. At that point, the two-segment switch was placed in "ARM." The flight director command bar immediately retracted out of view and the steer flag was displayed. The glide slope flag on the HSI also came into view. The autopilot was no longer tracking the glide slope and would respond to the pitch knob. This situation requires positive action on the part of the pilot. If the two-segment switch is turned off, the airplane can recapture the standard ILS with either the flight director or autopilot. If the mode selector of the flight director or autopilot is recycled with the two-segment switch remaining "ARMED," then the airplane can be flown level or climb to intercept and capture the upper segment. The pilot could also elect to abandon the approach. In each case, the warnings are adequate and the action required regardless of option desired, is positive.

4. Following the Two-Segment Guidance Without Localizer or Glide Slope

Approaches which pass through the two-segment area without passing through the ILS glide slope were flown at Stockton and at San Francisco. The two approaches were flown under the following conditions.

- (a) Aircraft is flying through area on track shown
- (b) Initial altitude 8000' AFL
- (c) ILS tuned
- (d) Two-segment switch "ARMED"
- (e) Airport elevation panel set/altimeter set
- (f) Auto modes selected
- (g) Approach configuration
- (h) Pilot follows guidance commands



FLYING THROUGH THE TWO-SEGMENT APPROACH AREA
(Aircraft configured for two-segment approach,
but not on ILS localizer)

FIGURE 7

B. 4. Continued

The airplane approached the terminal area on a track as illustrated in Figure 7. As the airplane reached the approximate 12 NM DME locus at 8000' above field elevation (derived in the computer by baro-corrected altitude minus airport elevation as set on the panel by the pilot), and with the airplane configured for a two-segment approach, the upper segment was captured and the pilot pitched the airplane down to follow the vertical commands and started tracking upper segment. The airplane maintained heading; the pilot continued to follow the two-segment computer guidance. The airplane flight path was the parabolic path shown at the bottom of Figure 7. All points on the flight path represent "on upper segment" values of DME and AFL. As drawn 4.5 NM DME is the closest point of approach to the DME on the track illustrated. As the airplane continues on heading, DME starts to increase. As it increases, the corresponding "on upper segment" altitudes increase, and the airplane is commanded to climb as shown.

If the airplane had moved in closer to the DME (as on the approach at San Francisco), the system would trip off when the 1.8 NM DME range was reached. If the airplane had approached within 500 feet AFL, again the system would have tripped off.

The area transit case (Figure 7) is technically possible but highly improbable operationally for two reasons:

- (a) It is doubtful that the pilot would have selected the auto mode(s) this prematurely although there is no technical constraint to prevent his doing so.
- (b) In such a case, the crew would certainly recognize that a commanded descent at that point is improper and take corrective action immediately.

In the more operationally probable case of a localizer offset, whether correction action is necessary would depend upon the ceiling and visibility. If the pilot had been cleared for his approach (high ceiling or VFR), no corrective action would be necessary. If he were required to fly to low minimums, he would desire the localizer and would have abandoned the approach.

B. 4. Continued

A two-segment autocoupled approach was made on a heading that would maintain the airplane just outside 1-1/2 dot deviation on the localizer. The localizer was not captured during this approach until the airplane was maneuvered to align with the runway at minimums. The upper segment was armed and captured at 6.8 NM and 2 dots deviation, 3076' above field level. The upper transition was normal as was the upper segment tracking. At 5 NM DME, the glide slope light illuminated AMBER. The glide slope captured at 732' above field level with 1.2 dots glide slope deviation and 2.3 NM DME. The autopilot and flight director followed the vertical path properly as in any other two-segment approach. Disturbances to the airplane did not cause any adverse affects to the approach. At 215' above field level, the autopilot was disengaged with the Captain's control wheel button. The autopilot disengaged, the flight director went to the Go-Around mode and the two-segment switch dropped to "OFF." The airplane was maneuvered to align with the runway and a standard missed approach was initiated as the airplane crossed the runway threshold.

5. Upper Intercept Altitude Limits

The two-segment approach system maximum design altitude is 14,000 feet MSL. When intercepting the upper segment above this altitude, the baro altitude signal is saturated and the resulting flight path would be slightly steeper than normally programmed. A two-segment autocoupled approach was initiated at 14,000' MSL. The upper transition appeared the same as the lower altitude transitions and the autopilot tracked the upper segment path the same as the tracking at lower altitudes. The increase in angle of descent is barely detectable.

When an approach was initiated at 2000' AFL, the system functioned normally. The glide slope light in the Approach Progress Display turned AMBER as soon as the upper segment was captured, as this was inside the 5 mile glide slope arm point. The lower capture and transition were normal.

B. Continued

6. Airspeed Schedule Limits

Airspeed variations have the same effect on the two-segment approach as they do on the standard approach. An airspeed increment of ± 10 knots does not show any perceptible change in the two-segment system performance. It is common practice to carry reference speed plus 15 knots on the upper segment and bleed that to reference plus 5 during the lower transition. The 10 knot airspeed bleed off will cause an autopilot approach to pass below the glide slope by 0.2 of a dot deviation at lower transition. If the airspeed bleed through the lower transition is 25 knots, the glide slope deviation reaches about 1/2 dot low.

7. Gross Weight, C. G. Limits

Two-segment autocoupled approaches were made with the gross weight at 113,700 lbs. and the center of gravity at 36% MAC, which is near the aft C. G. limit. At the glide slope capture point, a hard-over nose down signal was introduced to the autopilot. The pilot allowed the airplane to continue for one second after recognition, and then disengaged the autopilot and made a smooth pull up to level flight. The airplane flight path is plotted in Appendix II, Autopilot Nose Down Failure, together with the upper segment and glide slope. The maximum descent below the ILS glide path is 80 feet. A hard-over failure at 80 feet AG and no delay in recovery after pilot recognition resulted in negligible altitude loss (see Appendix II, Autopilot Nose Down Failure).

8. Engine-out Two-Segment Approach

A two-segment flight director approach was made during which the number one engine was retarded to idle to simulate engine failure. The approach is nominally flown at reference plus 15 knots on the upper segment and 30° flaps, so the airplane was already set in the engine-out configuration, as published in the Approved Flight Manual. The flight director commands are adequate to maintain the flight path. The airspeed was maintained at reference plus 15 on the upper segment, the lower transition, and the glide slope without any difficulty. The autopilot maintains normal

B. 8. Continued

control of the approach during simulated sudden engine failure on the upper segment. The motions produced are imperceptible and the airspeed is maintained easily with small increase power on the other two engines.

9. Component Failures

- (a) DME - The DME information is an essential part of the two-segment approach calculations and the loss of this signal will cause the autopilot, if in use, to disengage and the flight director fly bar to retract out of view. Turns up to 30° bank were made at 5000' and 1000' above the ground and there were no indications of any signal loss by the DME. The DME receiver and ground transmitter were failed and in both these instances, the autopilot disengaged and the flight director fly bar retracted out of view. The indications to the pilot are immediate and distinctive. The flashing autopilot disengage light and the flagged DME instrument adequately calls attention to the failure.
- (b) Air Data Computer - The Air Data Computer (CADC) circuit breakers were pulled with the airplane autocoupled and stabilized on the upper segment. The autopilot disengaged, turning on its flashing red warning light. The flight director fly bar retracted out of view, and the FD flag came into view. The servo altimeter flag was also displayed. The servo altimeter requires about two minutes to reset, due to unique implementation of a special D. C. potentiometer. The signal from the servo altimeter is an essential part of the two-segment calculations and must be valid for the system function. It is unlikely that a two to three minute waiting period can be tolerated while descending on a 6° path. Therefore, with a power interruption of the CADC with this type servoed altimeter installed, the two-segment approach should be abandoned until the units are restored and the system can be used again.

B. 9. Continued

- c. Two-Segment Computer - The two-segment computer was failed by pulling the two-segment computer circuit breakers. The immediate result was the same as the CADC failure. The system functioned normally within ten seconds after resetting the circuit breakers.
- d. Glide Slope - The glide slope receiver was failed by pulling the circuit breakers. This failure also caused the autopilot to disengage and the flight director fly bar to retract after the glide slope arm light came on. The glide slope flag in the ADI instrument came into view. When this failure was induced after glide slope capture and the HSI vertical deviation indicator had switched to glide slope, the HSI glide slope flag also appeared. The reaction of the system to failure of the ILS glide slope transmitter was the same as that of the receiver. The system would reset immediately upon restoration of the glide slope signal.
- e. Localizer - The vertical guidance of the two-segment system is independent of the localizer signal. The autopilot interlock requires a localizer valid signal in order to keep the roll channel engaged during an approach. The pitch channel will not engage unless the roll channel is engaged.

The localizer receiver circuit breakers were pulled and the autopilot disengaged with its flashing red warning light. The flight director fly bar remained in view and gave vertical guidance to follow the upper segment. There were no lateral commands. The fly bar remained wings level. The localizer light (VOR/LOC) on the Approach Progress Display went out. The upper segment light remained green. The glide slope amber light came on at about 5 NM DME and turned green at glide slope capture. The pitch commands were followed and produced the proper transition and tracking of the glide slope. When the localizer transmitter was failed, the autopilot did not disengage but maintained wings level. The vertical guidance continued. The NAV OFF flag and the ADI LOC flag were in view in both cases and the LOC lights were out on both the autopilot and flight director sides of the Approach Progress Display.

B. 9. Continued

- f. Switching Unit Failure - An analysis of the possible malfunctions of the two-segment switching unit is contained in the section titled "Failure Analysis of the Two-Segment Approach System Switching Unit" found in Appendix II.
- g. Safety Protectors Failure - Approaches were made with combinations of the safety protectors failed. When the 1.8 NM DME and the 500' AFL protectors are failed, the only remaining is the one-half dot protector and this insures that the pilot would be alerted if the transition to the glide slope was not started soon enough to prevent undershooting the glide slope. When the 1.8 NM DME and the 1/2 dot above glide slope are failed, the remaining protector will give warning for the minimum altitude of 500' AFL which gives the pilot adequate warning to initiate a Go-Around. When the 500' AFL and the 1/2 dot above glide slope are failed, the remaining 1.8 NM DME protector will warn the pilot that the proximity of the runway prevents completion of an ILS approach.

These protectors are very comforting to the pilot even though they may be over protective. The pilot still has the responsibility to monitor his position, altitude and airspeed and maintain his airplane in a good, safe environment at all times. The 1.8 DME and the 500' AFL protectors do not exist in any other approach system and the functions can be provided operationally by good piloting technique, so the question arises as to the need of these two protectors. The one-half dot above glide slope protector has a much more clearly defined function. The pilot is responsible for maneuvering the airplane from the upper segment to the glide slope via the transition provided or some other transition. If the airplane is within 1/2 dot and is not transitioning, the pilot must select some other transition immediately. The 1/2 dot distance is adequate for the pilot to make a satisfactory manual transition to a 3° descent path to landing. Therefore, the 1/2 dot protector serves a good purpose and provides the pilot adequate warning for his selection of the appropriate pilot action on the approach.

C. Autothrottle Operation

An autothrottle system was installed in the Ansett airplane and tested for airspeed tolerance. The system is required to hold airspeed within ± 5 knots of the airspeed index on the IAS indicator; the actual airspeed tolerance observed was ± 2 knots. Initially the autothrottle was to hold an airspeed increment while on the upper segment on command from the two-segment system. This increment was dropped when it was determined that better approaches resulted when airspeed was held constant throughout the approach.

The autothrottle displayed no tendency to run away during operation. Engaging the autothrottle with the airspeed index set 60 knots greater than the indicated airspeed resulted in a power surge to 1.85 EPR without any over temperature occurring. Engaging the autothrottle with the airspeed index set 60 knots below the indicated airspeed resulted in the power reduced to about 1000 pph for flow (minimum autothrottle position) which is about 1.03 EPR. In both cases the throttles start to adjust in anticipation of the selected airspeed. The throttles usually made two or three overshoots before stabilizing on the proper airspeed.

The autothrottle was tested for acceleration and deceleration while in cruise. The airplane was stabilized at 0.8 Mach, flight level 250, with a total air temperature $+8^{\circ}\text{C}$. The throttles were set at idle, the airspeed index at 0.8 Mach, and the autothrottle engaged. The engines took five seconds to reach 1.93 EPR. The airplane was in the same flight conditions, the airspeed index set at 200 knots, the throttles set at take-off thrust (1.93 EPR) and the autothrottles engaged. The throttles came back to the minimum setting and the engines decelerated to 1.03 EPR (1100 pph fuel flow) in 4.8 seconds.

While in cruise and under manual control with autothrottle on, the airplane was disturbed from stabilized flight. The autothrottles attempted to maintain a constant airspeed by reducing the throttles as the airspeed increased and increasing the throttles as the airspeed decreased. When the pitch attitude of the airplane was held reasonably steady, the throttles steadied down after moderate throttle movement. While under autopilot control, the airplane was disturbed from stabilized flight for a climb and descent. The autothrottles adjusted the power with moderate throttle movement so as to restabilize the airplane at the original speed.

C. Continued

The autothrottle disengages with either the #1 or #3 throttle button. The autopilot disengage button on the control wheels also disengage the system.

It requires approximately ten pounds of force to restrain the throttles from accelerating or to override and retard the throttles with autothrottle on. The force required to restrain the throttles from decelerating or to push them up while autothrottle is engaged is about eight pounds. These forces are moderate and acceptable.

The only indication of autothrottle engagement is the switch position and the activity of the throttles. If the autothrottle disengages, the autothrottle switch moves to OFF and the autothrottle disengage light (red) on the Captain's instrument panel illuminates. This light can be extinguished by pressing the #1 or #3 throttle buttons, pressing either autopilot disengage button, or pressing the light.

Although the system installed was not a current generation autothrottle, its accuracy in speed control was satisfactory and its use was acceptable for a standard ILS or the two-segment approach. The system does make some adjustments in anticipation of reaching an airspeed, but not as well as most pilots desire. Turbulence causes it to cycle with an aggressive response characteristic and the result is a chasing of the airspeed fluctuations. This is very undesirable from a ground noise standpoint and from a passenger comfort point of view. If the airspeed index is moved rapidly, the throttles will retard to their minimum setting until the lower airspeed is reached. The autothrottles usually do not anticipate the lower airspeed with sufficient margin to prevent an overshoot below the minimum desired airspeed and some consequent aggressive throttle action thereafter.

The use of autothrottle did not produce any reduction in noise level during a two-segment approach. Nor did it produce any reduction in pilot workload. The unhandy position of the airspeed index control (a knob on the Captain's airspeed indicator) caused an increase in pilot workload. It was the consensus of the pilots flying that the autothrottle was unnecessary and undesired for the B-727 in the two-segment approach. The autothrottle was therefore not installed in the on-line airplane.

D. Statistical Analysis

This analysis is made from 252 selected approaches flown during the Off-Line Pilot Evaluation portion of the Flight Test Program. The approaches were made in B-727-277 No. VII-RMU. All approaches selected were flown at Stockton, California, in January and February, 1973. The standard ILS had an intercept altitude of 1800 feet above field level. The two-segment approaches used all had a 3000' AFL intercept, a 6° upper angle and a 690' lower intersect altitude.

The selected approaches were called out from the stored data recorded during all flights with the parameters to be used in the analysis listed by DME distances from the transmitter between 9.0 and 0.3 nautical miles. The listings of all samples available were then screened and portions not part of the approach phase (before localizer intercept or after initiated go-around) were deleted together with scattered data points. The remaining samples were then used to compute averages and standard deviations for each parameter of each approach type at each distance point. On each of the statistical plots, the average value of the parameter is the center line (drawn point to point). The envelope drawn about the average is the one-sigma or 68% average. Simply speaking, 68% of the data points which were averaged for the center line fall within the envelope shown. An envelope of twice the width shown would encompass 98% of the data points.

The parameters analyzed in this manner are deviation shown on HSI, altitude above field elevation error, glide slope computer error, and DME distance error. Each of these parameters are plotted as variables versus DME distance.

Plot 7 is the HSI vertical deviation versus DME distance. This plot is an indication of how well the approach appears to the pilot. The flight director command bar is flown as closely as possible to the center position as the pilot can fly it. The raw deviation as shown on his HSI is plotted. Any error in this information remains and no attempt is made to correct it to any degree. Thus the plot represents what the pilot sees on his instrument.

This plot is made from 90 two-segment flight director approaches and 30 standard ILS flight director approaches. The HSI vertical deviation is plotted in dots deflection which is the displacement scale the pilot observes as he cross-checks the HSI while following the flight director commands. During the Off-Line Evaluation, the guest pilots flew one standard ILS and three two-segment approaches with the flight director. Therefore, the two curves displayed on Plot 7 were flown by the same pilots under the same flight conditions.

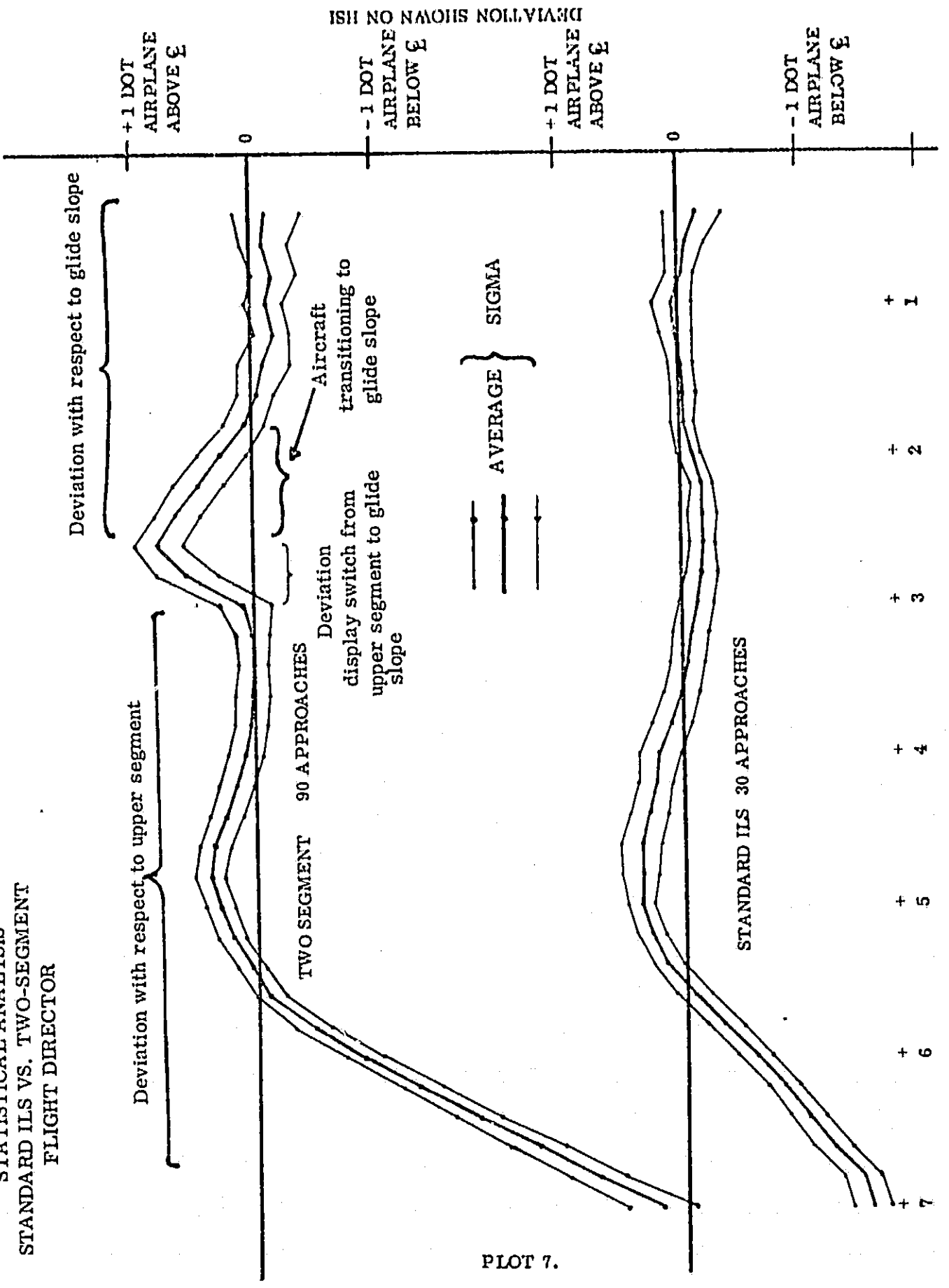
D. Continued

The standard ILS curve shows the airplane about 1-1/2 dots below the glide slope center line at 7.0 DME. The capture point occurs as the airplane reaches the center line and the ensuing transition results in about a 0.3 dot overshoot as the pilot follows the flight director bar. The overshoot is gradually corrected. A small overshoot (0.2 dot) below the glide slope center line occurs at 3.6 DME. The airplane slowly converges back to the center line at 1.8 DME and tracks very well from that point. The accuracy envelope varies from about 0.2 dots to 0.4 dots. This is good performance and acceptable for low visibility flight conditions.

The two-segment curve shows the airplane about 3 dots below the upper segment center line at 7 miles. This is about twice the deviation of the standard ILS, but the deviation moves across the HSI face twice as fast. The capture point occurs at about 6.4 DME with the deflection about 1-1/2 dots. With the rapid movement of the deviation as indicated and the large deviation at the capture point, the pilot has a difficult time using the deviation movement as an indication to configure the airplane for descent. The HSI deviation is not as useful in the two-segment approach as it is in the standard approach in this regard. The upper segment capture point occurs while the airplane is 1-1/2 dots below the center line and with the pitch down command starting at this point, the overshoot experienced is about the same as the standard ILS. The average value of the deviation converges to the upper segment center line very well between 3 and 4 NM. At about 3 NM DME distance, the lower capture occurs, the airplane starts pitching up to transition to the glide slope and the HSI vertical deviation switches to the glide slope. There is a small overshoot of about 1/8 dot as the airplane converges on the glide slope and that small deviation holds throughout the rest of the approach. The accuracy envelope is slightly larger than the standard ILS. It varies from about 0.2 dots to 0.5 dots. These two curves show the standard ILS as flown with the flight director, to be just a little more accurate than the two-segment. The two-segment does not have the tendency to overshoot as much as the standard ILS does.

NOTE: On the ILS glide slope 1 dot is .35° angular deviation. One dot equals 11 feet at .3 NM, and about 37 feet at 1 NM. On the upper segment the HSI deviation is a constant 250 feet per dot.

STATISTICAL ANALYSIS
STANDARD ILS VS. TWO-SEGMENT
FLIGHT DIRECTOR



PLOT 7.

D. Continued

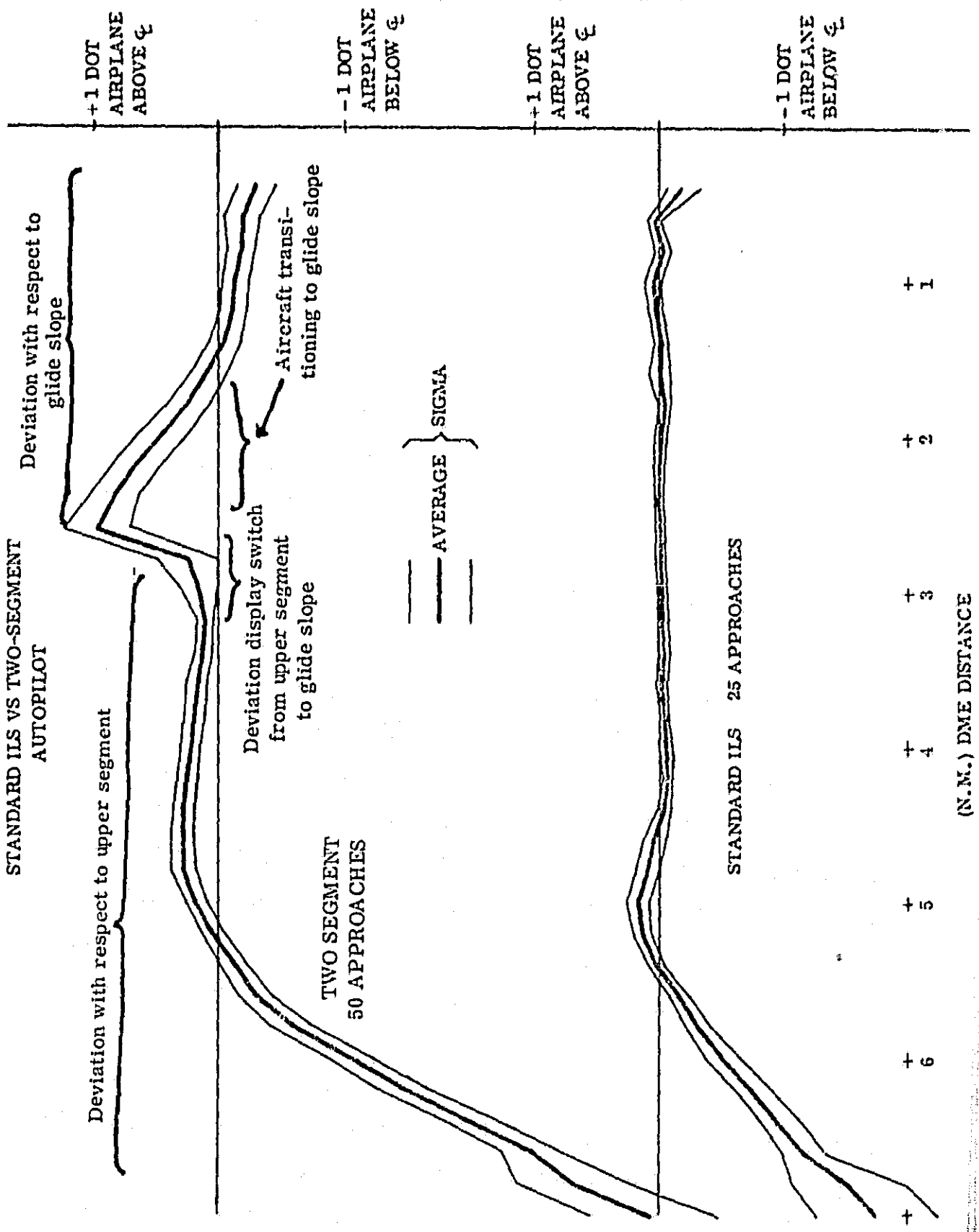
Plot 8 shows the autopilot performance on the standard ILS and the two-segment. Comparing Plot 8 to Plot 7 shows that the autopilot performance is much better than the flight director. On the standard ILS, there is a much smaller overshoot at the capture and a very small second overshoot thereafter. This second overshoot is probably too small to be noticed by the pilot. The glide slope tracking and accuracy envelope is also very good. The autopilot also improves the two-segment approach: the accuracy envelope is smaller as is the initial overshoot, although the autopilot does not converge back to the upper segment center line as fast as the flight director did. In fact, the average value was still $1/8$ dot (about 30 feet) above the center line when the lower capture occurred and the HSI deviation switched to glide slope. The autopilot's lower transition is slightly longer than the flight director (0.2 NM) and the average value passes through the glide slope center line and slowly departs from the center line. The deviation never gets very large ($1/4$ dot at 0.4 NM DME - about 4 feet). It should converge back to the center line, however, and not pass below it. This curve indicates that the amount of glide slope signal attenuation is a little too large inside 1-1/2 NM DME.

Plot 9 is above field level altitude error versus DME distance. The error is the difference between the above field level altitude computed by the two-segment system and the radar measured altitude. The curve shows the average error to be very small within 3.0 NM DME and the accuracy envelope to be within 15 feet. This indicates excellent performance between the servo altimeter and the airport elevation panel.

Plot 10 shows the DME distance error versus DME distance and it also shows the position and frequency of the upper and lower capture points. The upper capture occurred between 6.8 and 6.0 NM DME. The lower capture occurred between 3.0 and 2.2 NM DME. The DME distance error is the difference between DME range and the radar distance measurement. The average value is very nearly a constant 700 feet. This is slightly over 0.1 NM. This value is about what would be expected from the average DME transmitter. The accuracy envelope is about 500 feet wide. If the DME were tuned such that its signal error were zero, the ± 250 accuracy would cause a variation in the vertical position of the lower intersect altitude (and the upper segment position) of about ± 15 feet. As it is, the DME distance error can produce a vertical shift in the lower intersect altitude as much as 50 feet.

DEVIATION SHOWN ON ILS

STATISTICAL ANALYSIS
STANDARD ILS VS TWO-SEGMENT
AUTOPILOT

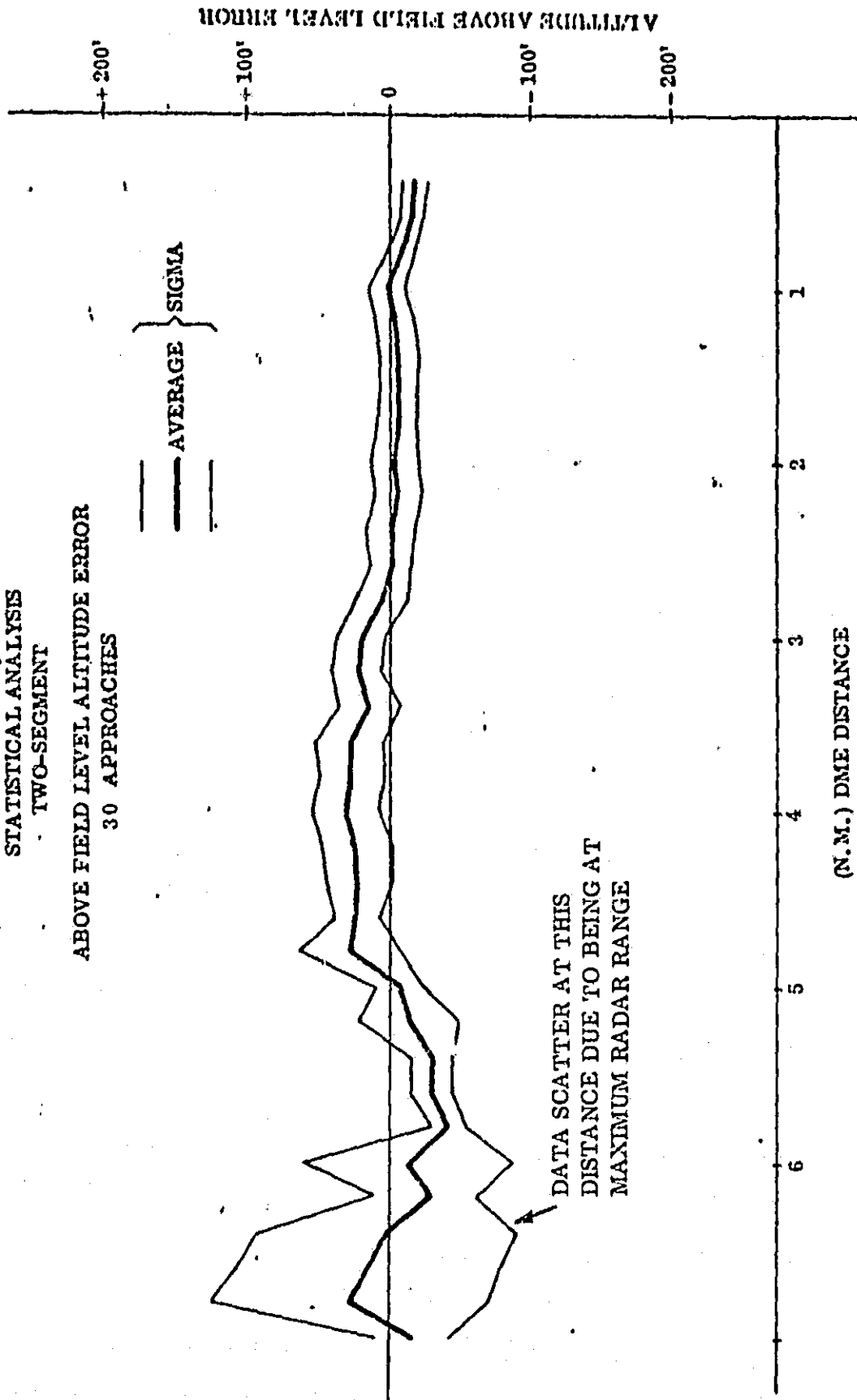


PLOT 8.

STATISTICAL ANALYSIS
TWO-SEGMENT
ABOVE FIELD LEVEL ALTITUDE ERROR
30 APPROACHES

— AVERAGE —
— SIGMA —

DATA SCATTER AT THIS
DISTANCE DUE TO BEING AT
MAXIMUM RADAR RANGE

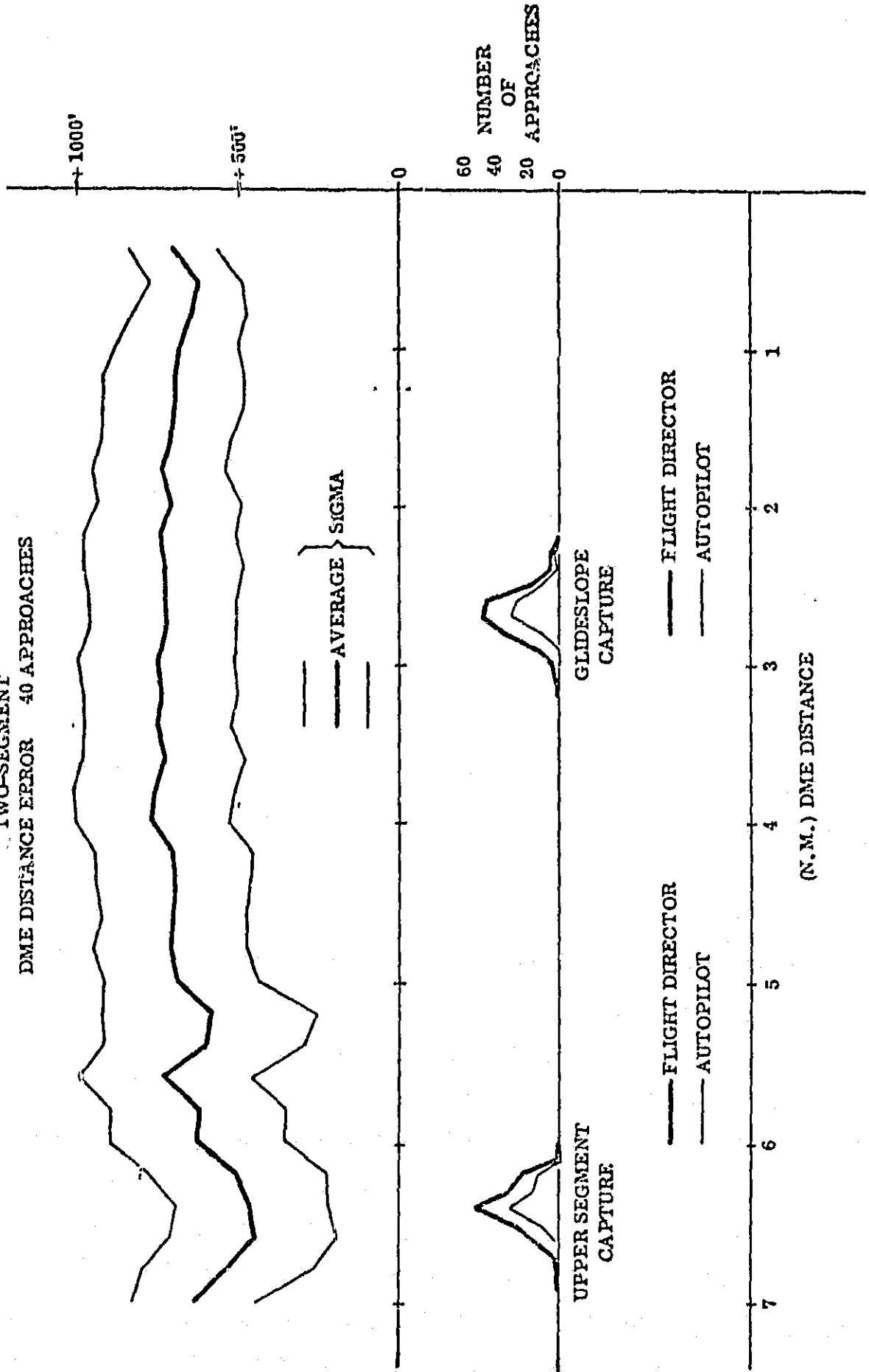


PLOT 9.

STATISTICAL ANALYSIS

TWO-SEGMENT

DME DISTANCE ERROR 40 APPROACHES

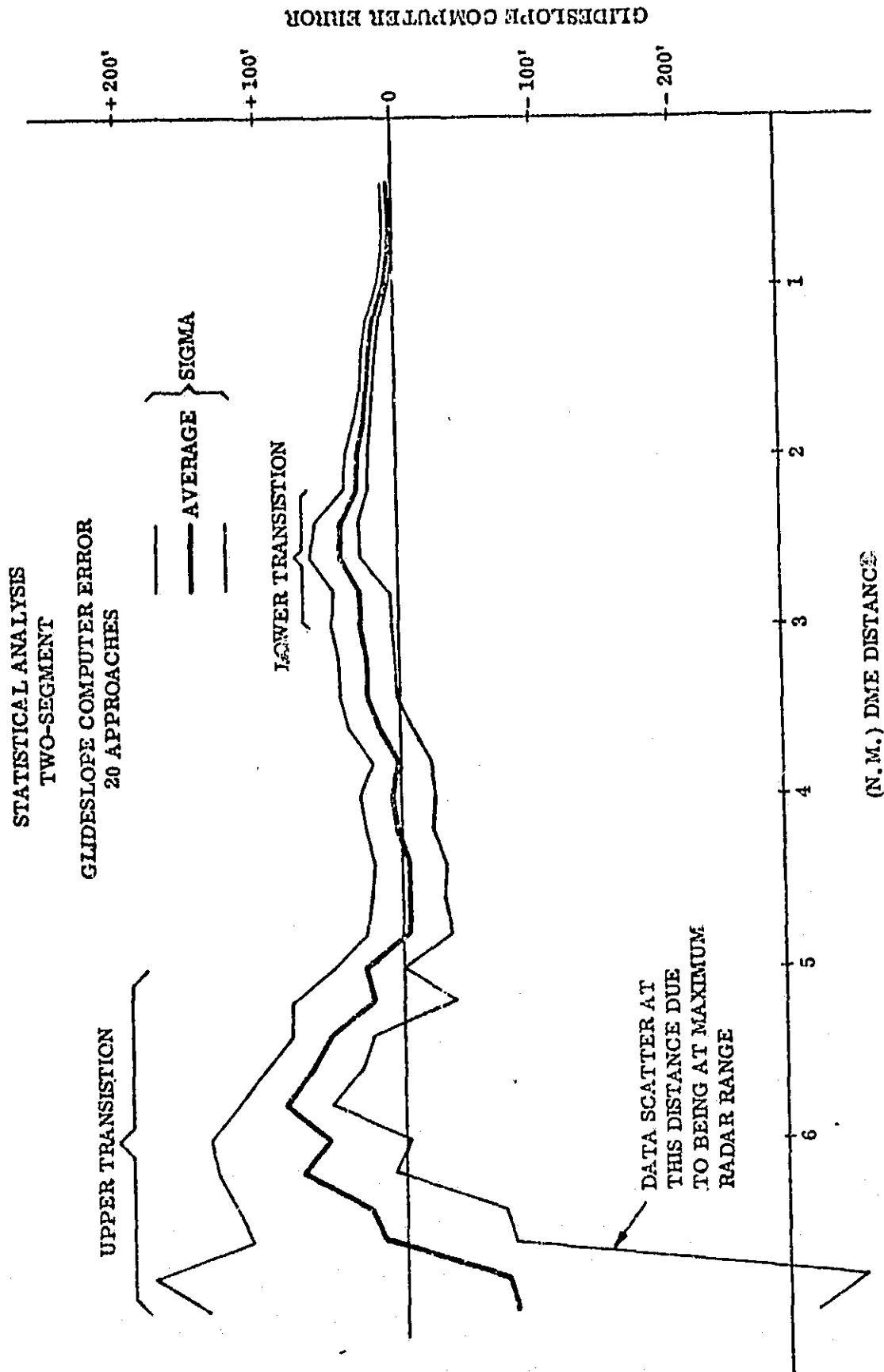


PLOT 10.

D. Continued

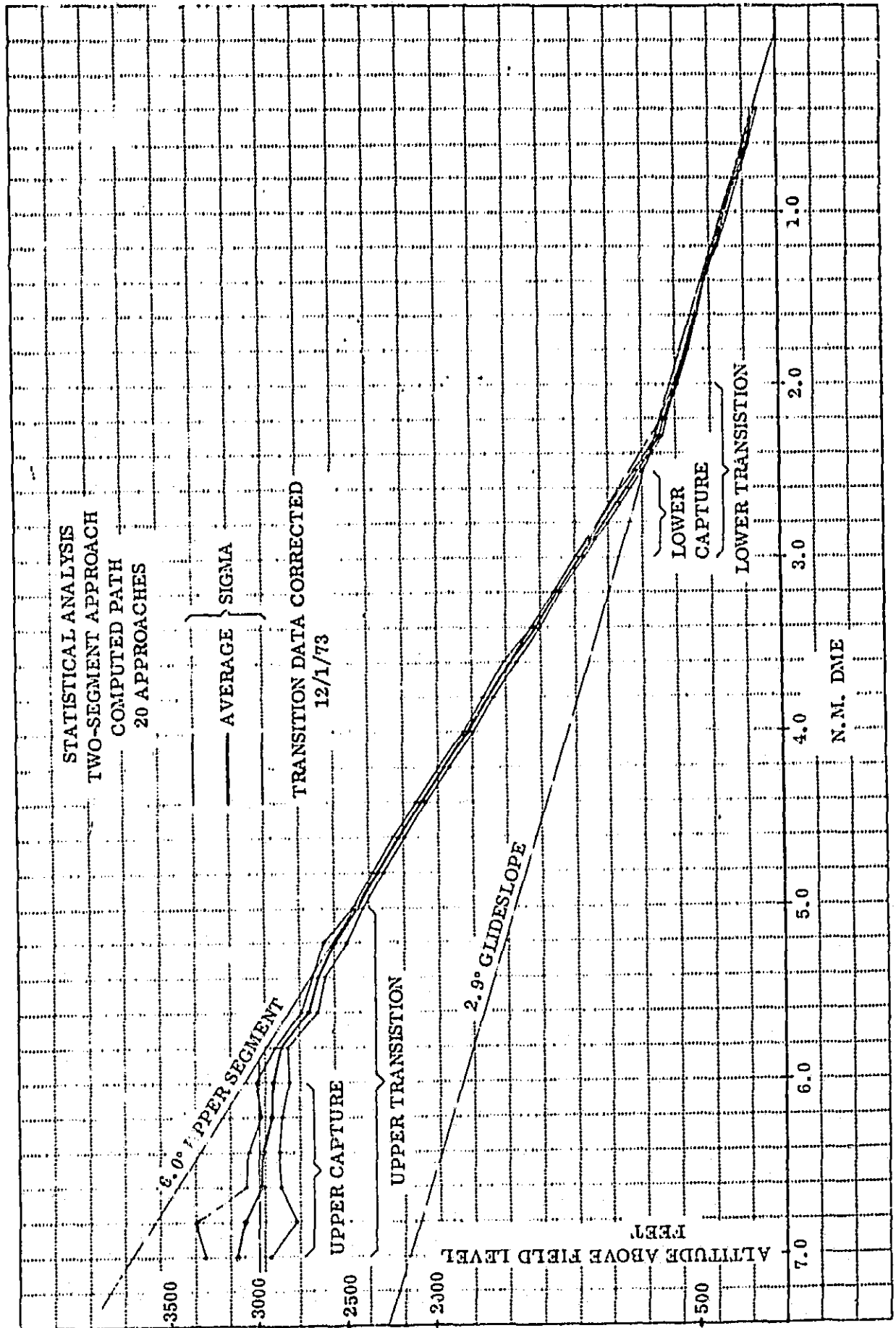
Plot 11 glide slope computer error versus DME distance shows the ability of the glide slope computer to produce the desired path in space. The glide slope computer error is the difference between the zero deviation path computed by the Collins equipment and the theoretical path. Examination of the curve indicates that the computer calculations are very accurate. The computer average error right after the upper transition is zero and increases up to 25 feet at the lower capture point. Following the lower transition that 25 foot error (at 2.0 NM DME) decays down to zero at about 1.0 NM DME. By plotting the glide slope computer error with respect to the theoretical path, one can see the vertical path in space that the glide slope computer produces.

Plot 12 is the glide slope computer error added to the theoretical path. The theoretical path is level at 3000' AFL intersecting the 6° path at 5.85 NM DME, down the 6° path to where it intersects the 2.9° glide slope which is 2.25 NM DME, then down the 2.9° glide slope to the glide slope transmitter (0 DME). Examining the curve between 5.0 NM DME and 3.0 NM DME shows a very well defined path that coincides very well with the theoretical path. From 2.2 NM DME to 0.3 NM DME indicates excellent definition of a path that coincides with the theoretical path. The calculated path as shown during the upper transition indicates a slow departure from the level portion and then a rapid bending down to an angle that converges with the well defined 6° path. This transition did prove satisfactory and acceptable to the pilots during the evaluation. At high speeds, however, the pitch-over did tend to be abrupt. The abruptness of the pushover might be caused by the bending in the middle of the transition. An improvement to the transition might be possible by defining a middle theoretical path of 3° between the level entry and the 6° upper path then phase into the 3° path and once on, it phases on to the 6° path. This would produce more rounding to the transition. The lower transition appears to be a pitch-up for a short time than a pitch-down to an angle shallower than the upper angle and one that slowly converges with the glide slope. One might suspect this path to produce the small deficiency observed in the transition as shown on Plots 7 and 8. The pitch command signal at the lower capture is for an immediate nose up, then later, a nose down to a shallower angle. It appears that the nose down signal required to follow this shallower angle until it reaches the glide slope is not replaced by a nose up signal soon enough. If the pitch-up command at lower capture were shallow and then the angle back to the glide slope were made even shallower, the result would be a smoothing of the path between the 6° upper segment and the glide slope.



PLOT 11.

NOTE: Positive glide slope computer error indicates theoretical path is above the zero deviation path desired by the computer.



PLOT 12.

D. Continued

The flight evaluation indicated that the airplane could fly a 6° upper segment quite adequately under most operational conditions encountered in airline operations. The approach was shown to be accurate and easy to fly and acceptable to airline pilots. So if a large airplane can safely fly a steep path from a high altitude to a low altitude, the only question a pilot could ask is how easily can he get the airplane onto and off of that steep path: thus, the transitions are the key to pilot acceptance once an angle for the steep path has been shown to be compatible with the airplane.